May River Watershed Action Plan Update & Modeling Report

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Prepared For

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Executive Summary

Background

The May River is designated as an Outstanding Resource Water by the SC Department of Health and Environmental Control (SCDHEC) and is valued particularly for its oyster production, aesthetic qualities, and recreational opportunities. The entire May River watershed is 13,477 acres and accounts for approximately 39% of the entire Town of Bluffton area. The May River watershed is divided into seven subwatersheds, with the Headwaters comprising 12,257 acres and includes four subwatersheds: Duck Pond (683 acres); Palmetto Bluff (1,926 acres); Rose Dhu Creek (4,168 acres); and Stoney Creek (5,480 acres). Development within the Town saw a rapid increase in population from 794 residents in 1990 to 12,530 people in 2010 and an estimated 25,557 people in 2019 (US Census Bureau, 2020). The resulting changes in land use over this time period saw an increase in impervious surfaces in the Headwaters of the May River from 5.78% in 2002 to 15.31% in 2018. The Rose Dhu Creek and Stoney Creek basins are the most impervious at 19.74% and 15.49%, respectively.

Simultaneously with increasing development, rising fecal coliform (FC) bacteria levels in the river's Headwaters have created water quality impairments for shellfish harvesting and necessitated the closure of the shellfish harvesting beds in this portion of the May River in 2009. Multiple agencies including SCDHEC, Beaufort County, and the Town of Bluffton, have been conducting rigorous monitoring for fecal coliform. The Town is also conducting microbial source tracking in the May River and in upland tributaries. The Town's microbial source tracking (MST) program has detected human, deer, and dog markers within the May River. As a result of field investigations, five failing septic systems have been eliminated in the Headwaters and there are plans to convert more areas to sanitary sewer in partnership with Beaufort County and Beaufort-Jasper Water and Sewer Authority (BJWSA). In addition to these sources of fecal coliform, results from recent studies (Sanger and Tweel et al., 2015; Montie, 2019), combined with the Town of Bluffton FC hotspot Water Quality monitoring program, indicate that increased stormwater runoff volume from development is a key contributor to both stormwater volume and pollutant loading in the May River.

This knowledge resulted in the Town developing a volume-based stormwater ordinance in 2010 and the May River Watershed Action Plan (Action Plan) in 2011. The Action Plan has a parallel approach to protect and restore shellfish harvesting throughout the May River and lists multiple strategies and project recommendations, primarily stormwater pond modifications or construction. The Town's priority has been to implement Action Plan projects and refine its understanding of what water quality improvements can be expected following completion.

Based upon the Action Plan, the Town has successfully secured five (5) EPA 319 Grant awards from SCDHEC for water quality improvement projects implementation. As of 2020, three (3) of these projects have been completed. The first award was used to construct the New Riverside Stormwater Pond in 2013 at one of the hot spots. While the pond effectively reduces fecal coliform concentrations by greater than 95% pre- versus post-treatment, there is no statistically significant decrease in fecal coliform concentrations measured ~1,700 linear feet downstream prior to discharging into the May River. The second 319 Grant for a stormwater volume-reduction Best Management Practice (BMP) project was completed in 2016 and is currently under evaluation.

This project retrofitted an existing stormwater system, permitted before the current volume-based ordinance, with volume control through stormwater reuse for irrigation.

Both of these 319 Grant projects contribute to a better understanding of the true impact of a BMP to improve water quality. The Town will continue to evaluate BMP technologies upon completion. Thus, every project will help the Town refine the Action Plan to be tailored for specific needs and conditions. The Action Plan is intended to be a living document with frequent updates and modifications. It will evolve over time so that successful recommendations and projects are highlighted and expanded on, while less successful and ineffective concepts are removed.

Based upon changing land use conditions throughout the May River watershed, state of knowledge surrounding fecal coliform latency in the environment, and quantified impact of BMPs to downstream water quality, the time has come for a May River Watershed Action Plan Update (Action Plan Update). The Action Plan must maintain consistency and alignment with other official plans and guidance documents, with the goal of protecting the May River Watershed. The Action Plan Update will consist of several simultaneous activities including:

1. Developing a regional, model Stormwater Ordinance & Design Manual;
2. Updating the Stormwater Utility (SWU) Fee Rate Model to project SWU Fee needs for operations, debt service for Capital Improvement Program (CIP) projects, and capital expenditures;
3. On-going fecal indicator bacteria (FIB) and microbial source tracking water quality monitoring;
4. Developing local ability to conduct qPCR microbial source tracking;
5. Completing long-term trend analysis and monitoring of new biological and physical indicators in the May River;
6. Completing a Water Quality Model (WQ Model) for baseline (2002) and current (2018) conditions for the May River watershed using XPSWMM to identify project locations and types. The model initially prioritizes completion of four sub-basins in the Headwaters where the current shellfish harvesting restrictions are located.

Using the WQ Model results and current state of knowledge, the 2011 Action Plan CIP projects will be evaluated in terms of the potential reduction of fecal indicator bacteria (FIB). Cost estimates to implement a total of eleven (11) projects with the highest potential to remove FIB will be developed to inform the Town's SWU Fee and long-range CIP budget. These projects will arise from the 2011 Action Plan project evaluations and new projects resulting from the WQ Model.

FC bacteria persist in fresh water, and the volume of fresh water entering a receiving water body increases with the amount of development on the land. A recent study (Montie et. al., 2019) of the May River (Appendix A) concluded that developed and deforested lands have higher levels of freshwater input into estuaries, which leads to decreased salinity levels. Furthermore, FC levels were higher when salinity levels were lower and this relationship was strongest at SCDHEC sampling stations closest to the Headwaters (Montie et al., 2019). Other studies of tidal creek systems along the coast of South Carolina (Holland et al., 2004; Sanger et al., 2008; and Sanger and Blair et al., 2015) have found that when the impervious cover exceeded 10-20% in a watershed, measurable physical and chemical changes were observed such as altered hydrography, increased salinity variance, altered sediment characteristics, increased chemical contaminants, and increased fecal coliform loadings. Furthermore, measurable impacts were observed in living resources and ecological processes when impervious cover exceeded 20–30%. Health risks and flooding vulnerability of a headwater region become a concern when impervious cover exceeds 10-30%.

Project Findings and Interpretations

Impervious surfaces include roads, buildings, parking lots, and stormwater ponds. In the 2002 baseline condition, the predominant land covers in the subwatersheds contributing to the Headwaters of the May River (the Duck Pond, Palmetto Bluff, Rose Dhu Creek, and Stoney Creek subwatersheds), were evergreen forest (35.55%) and woody wetlands (33.35%). The total amount of developed lands amounted to 1,307.44 acres (10.67%). Within the 123 subcatchments in the Headwaters subwatersheds, 97 were less than 10% impervious; 19 were between 10-20% impervious; and 7 were between 20-30% impervious. The amount of development in each Headwaters' subwatershed, from least to greatest amount, was Duck Pond (9.13%); Stoney Creek (9.63%); Palmetto Bluff (9.66%); and Rose Dhu Creek (12.75%).

In the current 2018 condition, the predominant land covers in the Headwaters subwatersheds of the May River are still evergreen forest (25.71%) and woody wetlands (30.22%). However, the total amount of developed lands amounted to 3,765.46 acres (30.72%). As a result of development, of the 123 subcatchments in the Headwaters subwatersheds, 62 are 0-10% impervious; 28 are 10-20% impervious; 26 are 20-30% impervious; and 7 are more than 30% impervious. The amount of development in each Headwaters subwatershed, from least to greatest amount, is Duck Pond (8.85%); Palmetto Bluff (18.37%); Stoney Creek (25.01%); and Rose Dhu Creek (47.52%). The slight decrease in developed land in Duck Pond is the result of some of the developed open space being classified as either shrub/scrub by the National Land Cover Database.

In order to understand the underlying causes of the FC impairments in the May River Headwaters, and the extent to which development has contributed to them, McCormick Taylor and Moffatt & Nichol analyzed changes in baseline (2002) and current (2018) conditions which involved an analysis of multiple data sources including land use, impervious surfaces, meteorological data, soils, channel network, and water quality monitoring data. A water quality model was developed with the XPSWMM software and calibrated using available monitoring data.

Watershed loading models are subject to high levels of variability and uncertainty. The model itself is an approximation of reality and the model parameters can only be estimated. There is natural variability in land use and cover, meteorology, and management across the watershed. Next, monitoring data provide an imprecise target for model calibration, as laboratory results have their own associated uncertainty based on surface water grab samples providing a measure of water quality at the moment in time when the sample is collected, which may not be fully representative of daily average model predictions. Calibration thus consists of comparing two uncertain numbers, the monitored value and model value.

The XPSWMM model estimates stormwater runoff and FC concentration based on land use (natural land cover, low/medium and high intensity development, presence of septic vs. sanitary sewer systems), impervious cover, infiltration of soils, groundwater flow, and meteorological information (precipitation and evapotranspiration). This model was calibrated using available monitoring data. This report discusses ways that the Town can enhance and improve existing flow and fecal indicator bacteria monitoring efforts, which can be used in the future to recalibrate and refine the existing XPSWMM model. For this project, XPSWMM's Runoff and Sanitary modes were utilized to model both hydrologic behavior and FC concentrations. The net effect of all structural BMPs in the May River Headwaters watersheds model is implicit in the model results (as a function of land use and water quality calibration) at the outlets. In order to allow all users to evaluate the effectiveness of BMPs it was determined that use of the Watershed Treatment Model (WTM, a tool developed by the Center for Watershed Protection) would be the most accommodating option. The decision not to model BMPs in XPSWMM was the result of extensive consultation with the software developer's technical support advisors, who emphasized that XPSWMM modeling both water quality and hydraulics simultaneously is limited. Despite this limitation, the Team still believes that this model is a useful tool that will allow the Town to estimate the effect of current and future BMPs.

The XPSWMM water quality simulation model calculated FC concentrations for the outfalls at each of the four major subwatersheds every seven minutes for an entire year (2002 and 2018). Laboratory measurements of FC are typically given as "most probable number" (MPN) per 100/mL or as colony forming units (CFU) per 100 mL. Both units are equivalent but reflect different EPA approved methodologies for counting bacteria cells. For purposes of this report, to distinguish modeled estimates for bacteria, all results were given as "number of FC" (#) per 100/mL. In Regulation 61-68 Water Classifications and Standards, SCDHEC provides limits for FC concentrations for all water use designations. For shellfish harvesting in Outstanding Resource Waters (ORW), such as the May River, these limits are either for a daily maximum concentration (43 MPN/100 mL) or a monthly average (14 MPN/100 mL).

The modeled average daily maximum FC concentrations in all four subwatersheds were above the SCDHEC threshold. In 2002, the XPSWMM water quality model estimated the average maximum daily FC concentrations (the yearly average of the highest predicted FC concentration for each day) as 583 #/100mL for Rose Dhu Creek; 749 #/100mL for Palmetto Bluff; 827 #/100mL for Duck Pond; and 995 #/100mL for Stoney Creek. In 2018 the model estimated daily maximum FC concentrations in the four subwatersheds as 538 #/100mL for Duck Pond; 650 #/100mL for Rose Dhu Creek; 687 #/100mL for Palmetto Bluff; and 932 #/100mL for Stoney Creek.

Although the modeled FC concentrations are generally higher in 2002 than 2018, the total modeled bacteria load is lower in 2002 as a result of a very large increase in water volume in 2018 (585% increase in annual water volume for the entire Headwaters Watershed region). The increase in runoff is a result of the changes in land use such as the conversion of undeveloped, natural areas to those with more impervious surfaces (in the May River Headwaters, the total amount of impervious surfaces increased from 708 acres in 2002 to 1,876 acres in 2018). This model output is supported by an analysis of SCDHEC monitoring data from 1999 to 2017 in the May River (Montie et al., 2019) which found that FC levels at locations closest to the Headwaters were well above the approved SCDHEC shellfish water quality standard. Additionally, the data showed that FC levels were higher when salinity levels were lower, and this relationship is strongest at SCDHEC sampling stations closest to the Headwaters. Finally, FC levels in the Headwaters increased as population levels grew in the Town of Bluffton, and this relationship was strongest at SCDHEC sampling stations closest to the Headwaters.

The FC load for each subcatchment in each subwatershed is calculated by multiplying the concentration by the corresponding water volume at each time step in the model. In addition to calculating the total load for each subcatchment in the four subwatersheds, the Team also calculated the normalized load (total load divided by the subwatershed area) and rate of change in load (comparison between 2002 and 2018 conditions). In 2002, the XPSWMM water quality model results showed that Stoney Creek had the subcatchment with the greatest FC load and the average overall FC load was greatest in Stoney Creek subcatchments. In 2018, Rose Dhu Creek had the largest subcatchment load and average load. In general, the modeled results showed that total load for each subwatershed, as well as the average subcatchment load, increased by one to two orders of magnitude from 2002 to 2018. All ten of the subcatchments with the highest FC loads are found in subcatchments in the Stoney Creek or Rose Dhu Creek subwatersheds, and all were the same order of magnitude (10^{13} colonies of FC). The normalized loading for all four subwatersheds was on the same order of magnitude for 2002 (10^{9} bacteria/acre) and 2018 (10^{10} bacteria/acre), meaning that the normalized loading was ten times higher in 2018. Stoney Creek had the highest maximum and average normalized loading for both 2002 and 2018.

Bacteria hotspots in the May River Headwaters were identified as the ten subcatchments that had the highest total FC load, highest normalized FC load, and the greatest rate of change from 2002 to 2018. Two subcatchments (SUB-RD-09 and SUB-RD-12) appeared on all three lists. Three subcatchments (SC103, 106, and 112) are listed on both the top total FC load and top normalized FC load.

State of Knowledge Concerning FC Fate and Transport and BMP Efficiency

Because measured FC concentrations are above threshold limits for shellfish harvesting for the May River, the Project Team recruited environmental microbiology expert Dr. Rachel Noble to provide context and recommendations. Dr. Noble's experience with FIB in other coastal communities in North and South Carolina has shown that fecal indicating bacteria (FIB) do not correlate well with the occurrence of pathogens, and they do not identify the source of the contamination. In other words, it is possible to find populations of FIB in the environment that are separate from fecal material and are not associated with a risk of illness. Additionally, many studies – including monitoring efforts by the Town of Bluffton – have documented that FIB can colonize and regrow in biofilms and sediments in the storm drainage system. These constraints of FIB further limit the ability to track the original source of contamination (Burkhart, 2012). In general, human sewage contamination presents the greatest health risk and is a controllable source (fix underperforming septic systems and/or sanitary sewer conveyance systems) to reduce the risk of human exposure to pathogenic viruses and bacteria.

Available information from research indicates that BMP efficiency is variable and dependent on the design, maintenance, and other factors. For example, in some cases a net export of microbes can result due to improper maintenance, regrowth of microbes in the BMP, resuspension during storm events, or direct wildlife deposits (Characklis et al., 2009). Information regarding removal rates of FIB in the International BMP Database (Clary et al., 2010) are variable and dependent on the following, 1) season in which the FIB were quantified; 2) stormwater volume and flows; and 3) the type of FIB being measured. Removal values in coastal SC will most likely be lower than those included in the International BMP Database, which has many studies based on the West Coast. Dr. Noble informed the Project Team and the Town that this is primarily due to 1) SC temperature is higher during most seasons than in west coast environments; 2) SC water sources tend to be blackwater and tannic water, which reduces light penetration; and 3) persistent forms of FC are known to grow in the sediments of systems in SC. Furthermore, Dr. Noble stressed that research has called attention to the nature of temperature-warm, nutrient-rich, stagnant BMPs systems that appear to serve as a reservoir of FIB and at times may also preferentially grow the fecal indicator bacteria.

The International Stormwater BMP database contains approximately 600 pairs of influent and effluent data for fecal coliforms and E. coli. across multiple states. Clary et al. (2008) analyzed the fecal coliform and *E. coli* data and showed that swales and detention basins did not appear to effectively reduce FIB in effluent samples. Datasets for wetlands and manufactured devices were not of adequate size to draw meaningful conclusions, but sometimes these systems showed bacterial growth. The authors concluded that the ability of BMPs to reduce FIB varies widely across BMPs. No single BMP appears to consistently reduce FIB concentrations. Among the BMPs, retention pond and media filters appeared to show some positive trends, but these were not across the board. Additionally, high removal efficiency by a BMP does not always guarantee attainment of bacteria standards when inflow concentrations are high (Wood, 2018). Thus, FIB reduction BMPs may not consistently reduce FC concentrations downstream in receiving waterways.

Faced with these challenges of bacterial regrowth, varying BMP removal efficiencies, and potentially high inflow FC concentrations that cannot be reduced to attain bacteria standards, there is a movement away from stormwater ponds to reduce bacteria loads downstream across the southeastern region. Instead, other practices that encourage runoff reduction are increasingly emphasized. Runoff reduction is defined as "the total annual runoff volume reduced through canopy interception, soil infiltration, evaporation, transpiration, rainfall harvesting, engineered infiltration, or extended filtration."

Locally, the reduction of FC concentration and downstream efficacy of the New Riverside Pond, a stormwater pond BMP, has been studied by the Town and researchers at University of South Carolina-Beaufort (USCB). The results of this analysis showed that there was a statistically significant reduction in FC concentrations between the pond influent and pond effluent. Additionally, there was a statistically significant reduction in FC concentrations at a short distance downstream of the pond outlet, for observations before and after the pond was constructed. However, at the outfall to the May River, the was no statistically significant reduction in FC concentrations before and after the pond was constructed. In other words, even though a large stormwater treatment BMP was installed and effectively removed FC, there was not a benefit to the May River because the bacteria levels still increased downstream of the pond.

In particular, in the face of climate change and sea level rise, it has been important to begin to place tidal influence into the context of stormwater conveyance. The impact of higher tidal elevations in low-lying regions such as SC coastal Lowcountry cannot be overstated. This is because the extreme high tides, also known as perigean or king tides, interfere with the conveyance of stormwater to receiving waters. The rising tides have the capability of interfering with stormwater conveyance into receiving waters; adversely impacting sanitary sewer pump station and septic system drain field functionality; creating more frequent or longer duration flooding during storm events; inundating water, wastewater, and stormwater infrastructure by daily high tide (which promotes corrosion and pipe damage, as well as can impede the flow of both stormwater and wastewater conveyance systems); and elevating groundwater levels and increasing saltwater intrusion. There are multiple ways to address tidal influence at the outset, including installing check valves, locating sewer mains outside of tidally flooded areas, removing debris in problem areas, and promoting infiltration in creek and watershed restoration plans. Of initial importance are identifying thresholds at which the performance of the sewage and stormwater conveyance system are compromised.

Recommendations

Recommendations in this report include:

1. Detailing strategies to address current data gaps uncovered during the water quality model development and calibration (§3.0);
2. Establishing future monitoring to assess and calculate bacteria loading (§5.1);
3. Implementing projects, programs and policies that reflect the current state of knowledge regarding stormwater treatment (§5.2) and potential partnerships;
4. Evaluating the remaining proposed 2011 Action Plan projects for relevance under current conditions (§5.3); and
5. Proposing new projects, cost estimates, and ranking/prioritization of these projects to consider for inclusion in the Town's long-range CIP budget (§5.4).

In general, the recommended strategies involve Four Ps: Partnerships, Policies, Programs, and Projects. Overall, the goal will be to follow Better Site Design principles to conserve natural areas including tree canopy, reduce impervious cover, and manage designated stormwater reduction volumes by infiltration and/or filtration techniques as first priority, or other approved volume reduction techniques as second priority. These strategies are in agreement with local research (Holland et al., 2004; Sanger et al., 2008; Sanger and Blair et al., 2015; Sanger and Tweel et al., 2015; Montie, 2019) pertaining to the negative impacts of impervious surfaces in southeastern estuarine environments and are supported with design guidance (such as *Low Impact Development in Coastal South Carolina: A Planning and Design Guide*, Ellis et al., 2014) and in local ordinances. The Town of Bluffton is currently in the process of adopting a new regional stormwater design manual and ordinance with Beaufort County, Jasper County, the City of Beaufort, City of Hardeeville, and Towns of Port Royal and Yemassee.

Partners

The Town should continue to seek and formalize partnerships with a variety of organizations to protect and improve water quality in the May River watershed. These organizations may include Federal, State, County, Academic Institutions, Non-Governmental Organizations and Private Commercial Properties. The level of partnership required may range from short-term, project-specific agreements to long-term Memorandums of Agreement or Understanding to accomplish Action Plan Update objectives.

Policy

Overall, the goal for the Town of Bluffton should be to follow Better Site Design principles to conserve existing natural areas and tree canopy, reduce impervious cover, and manage designated stormwater reduction volumes by infiltration and/or filtration techniques as first priority, or other approved volume reduction techniques as second priority. These strategies are in agreement with national and local research pertaining to the negative impacts of impervious surfaces in southeastern estuarine environments, and are supported with design guidance, such as *Low Impact Development in Coastal South Carolina: A Planning and Design Guide* (Ellis et al., 2014) and *Southern Lowcountry Stormwater Design Manual* (Center for Watershed Protection and McCormick Taylor, 2020).

Policies to protect and improve water quality in the May River watershed include:

1. Adopt proposed regional *Southern Lowcountry Post Construction Stormwater Ordinance and Design Manual.*
    a. The Town should incorporate volume reduction BMPs (those that encourage infiltration) within existing and future CIP projects to the maximum extent practical, especially for project locations with well-drained soils (Hydrologic Soil Group A or B)
2. Eliminate clear cutting approach within developed areas.
3. Increase buffer areas and requirements.
4. Increase conservation and open space requirements and require recorded conservation easements.
5. Reduce planned density/re-zone.
6. Increase tree protection/conservation areas and requirements
    a. Increase tree protection area from drip line to an additional 25' from drip line.
7. Offer incentives to renegotiate existing land development agreements to reduce density and meet current environmental objectives.
8. Develop strategies to effectively execute public/private partnerships.

Programs

Continuing and new program recommendations intended to protect and improve water quality in the May River watershed include:

1. Continue to support the Municipal Separate Storm Sewer System (MS4) program in the Town and County as they work to achieve the six (6) Minimum Control Measures.
2. Neighborhood Assistance Program
    a. Septic System Assistance Program to assist Town residents with septic system maintenance to ensure proper functioning until sanitary sewer connections are available.
    b. Septic to Sewer Conversion Program to assist Town residents with offsetting the potential costs to abandon existing septic systems and connect to available public sanitary sewer.
3. Establish an Impervious Area Restoration/Retrofit Program in areas where development pre-dated stormwater management requirements or failed to meet on-site retention of the 95th percentile storm. The purpose of this Program is to target large impervious areas to be retrofitted to meet 95th percentile storm retention of impervious surfaces with infiltration/filtration BMP to the maximum extent possible.
4. Water Quality Monitoring Program modifications include
    a. Developing in-house microbial source tracking
    b. Recommendations for future bacteria monitoring locations
    c. Recommendations for future water flow monitoring locations

Projects

Stormwater ponds are the predominant structural BMP utilized in the May River Headwaters. The total number of ponds has increased from 22 in 2002 to 262 in 2018. In a departure from the recommendations from the 2011 Action Plan, ponds and ditches are not recommended as BMP practices to address the fecal coliform bacteria impairment in the May River. Although they do provide important services for flood attenuation and some pollutant removal, they do not promote the infiltration of precipitation, and thus do not provide any runoff reduction (refer to *Southern Lowcountry Stormwater Design Manual*). Stormwater enters the system and leaves at a controlled flowrate, which is advantageous for flood protection, but may not prevent the persistence of FIB downstream of the practice (as has been documented in the literature and the Town's monitoring data). Recommendations are provided that detail criteria to "retrofit" existing ponds to achieve FC reduction and WQ improvements.

Four (4) septic to sewer conversion projects were evaluated in the Rose Dhu Creek and Stoney Creek subwatersheds: Cahill, Gascoigne, Stoney Creek, and Pritchardville. These projects overlap with 42 subcatchments in the Stoney Creek watershed and 11 in Rose Dhu Creek. Based on WQ Model outputs, these projects alone may potentially reduce FC loading by 3.46×10^{13} FC per year.

As part of the Project Scope, eleven (11) project sites (incorporating various individual BMPs) were selected in consultation with the Town (prioritizing subcatchments with FC bacteria hotspot and/or large impervious areas). These sites were evaluated in terms of the potential benefits gained by retrofitting to meet the 95th percentile storm retention, to the maximum extent possible, under the proposed Impervious Area Restoration/Stormwater Retrofit Program. All 11 projects were in Rose Dhu Creek (6 projects) and Stoney Creek (5 projects). These included: Bluffton Early Learning Center (BELC); Boys and Girls Club of Bluffton (BGC); Benton House (BH); Bluffton High School (BHS); Buckwalter Recreation Center (BRC); Lowcountry Community Church (LCC); McCracken Middle School/Bluffton Elementary School (MMSBES); May River High School (MRHS); One Hampton Lake Apartments (OHLA); Pritchardville Elementary School (PES); and Palmetto Pointe Townes (PPT).

The project team in consultation with the Town decided that the spreadsheet-based tool, the Watershed Treatment Model (WTM), allowed for flexibility to quickly analyze and evaluate a variety of stormwater BMPs, including permeable pavement, bioretention, green roofs, rainwater harvesting, filters, and infiltration trenches and chambers. In order to narrow down the extensive list of potential restoration projects to highlight priorities for the May River Headwaters Watersheds, an evaluation matrix was developed (Section 5.4.5 of this report). Each project was scored with respect to feasibility for cost (20 points), location within a subcatchment flagged as a FC bacteria hotspot (10 pts.), subcatchment imperviousness (10 pts.), potential bacteria load reduction (20 pts.), potential runoff reduction (15 pts.), maintenance requirements (15 pts.), potential for agreeable partnerships with landowners (10 pts.), amount of effort required for permitting (15 pts.), how well the surrounding community will respond to the project's installation (10 pts.), and ease of access to the site for both construction and maintenance (10 pts.).

If all 15 of the proposed projects were implemented, the XPSWMM and WTM model results indicate there is the potential to remove 1.67×10^{14} FC bacteria/year from stormwater (for Full stormwater retention volume (SWRv)) or 2.53×10^{14} FC bacteria/year (Reduced SWRv scenario). This is about 35% and 30% of the 2018 FC load for all four subwatersheds in the May River Headwaters.

All of the septic to sewer conversion projects and stormwater retrofit projects were located in the Rose Dhu Creek and Stoney Creek subwatersheds. The total FC load in 2018 for these two subwatersheds was 3.95×10^{14} FC bacteria/year, which accounts for about 83% of the bacteria load for the entire May River Headwaters. The estimated goals for FC reduction in these two subwatersheds are 96.1% and 97% for Rose Dhu Creek and Stoney Creek, respectively, to meet the daily maximum concentration threshold for shellfish harvesting (43 MPN/100 mL). The combination of septic to sewer conversion with the Full SWRv provides about 50% reduction, which is about half of what would be necessary in these watersheds.

The potential benefits of recommended projects was estimated to be 3.46×10^{13} FC reduction for septic to sewer conversion (only calculates benefits of sewer conversions within the Headwaters), 2.99×10^{14} FC reduction for the Full SWRv stormwater retrofit projects, and 2.53×10^{14} FC reduction for the Reduced SWRv projects. The estimated costs of these projects are $20.8 million for septic to sewer conversion (based on 2019 BJWSA cost estimates); $32.7 million for the Full SWRv projects; and $22.6 million for the Reduced SWRv projects.

Additional recommended types of projects beyond the eleven that were modeled include:

1. Impervious Surface Rehabilitation/Retrofit
2. On-site Volume Reduction
3. Modifications to Make Ponds Bacteria Neutral (Pond Retrofit)
4. Proprietary Products to Eliminate Bacteria
5. Nature-Based Solutions

1.0 Introduction

1.1 Project Overview

The May River is designated as an Outstanding Resource Water (ORW) by the SC Department of Health and Environmental Control (SCDHEC) and is valued particularly for its oyster production, aesthetic qualities, and recreational opportunities. Located within the jurisdictional limits of the Town of Bluffton and Beaufort County, the May River Watershed is approximately 13,477 acres and is divided into seven basins, also referred to as subwatersheds (Figure 1). Over nearly the past two decades, rising fecal coliform (FC) bacteria levels in the river's Headwaters have created water quality impairments for shellfish harvesting and necessitated the 2009 closure of portions of the SCDHEC shellfish harvesting beds in the May River Headwaters (Figure 2).

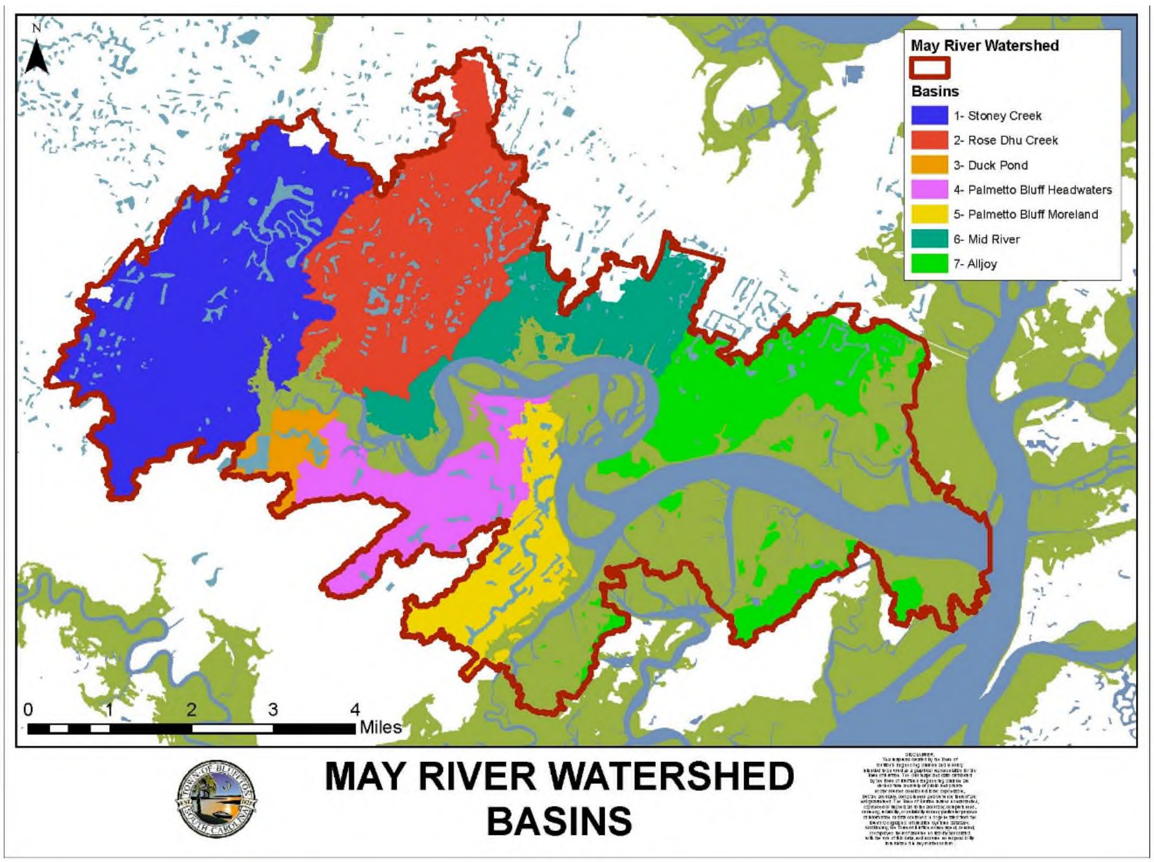

Figure 1. May River Watershed Basins

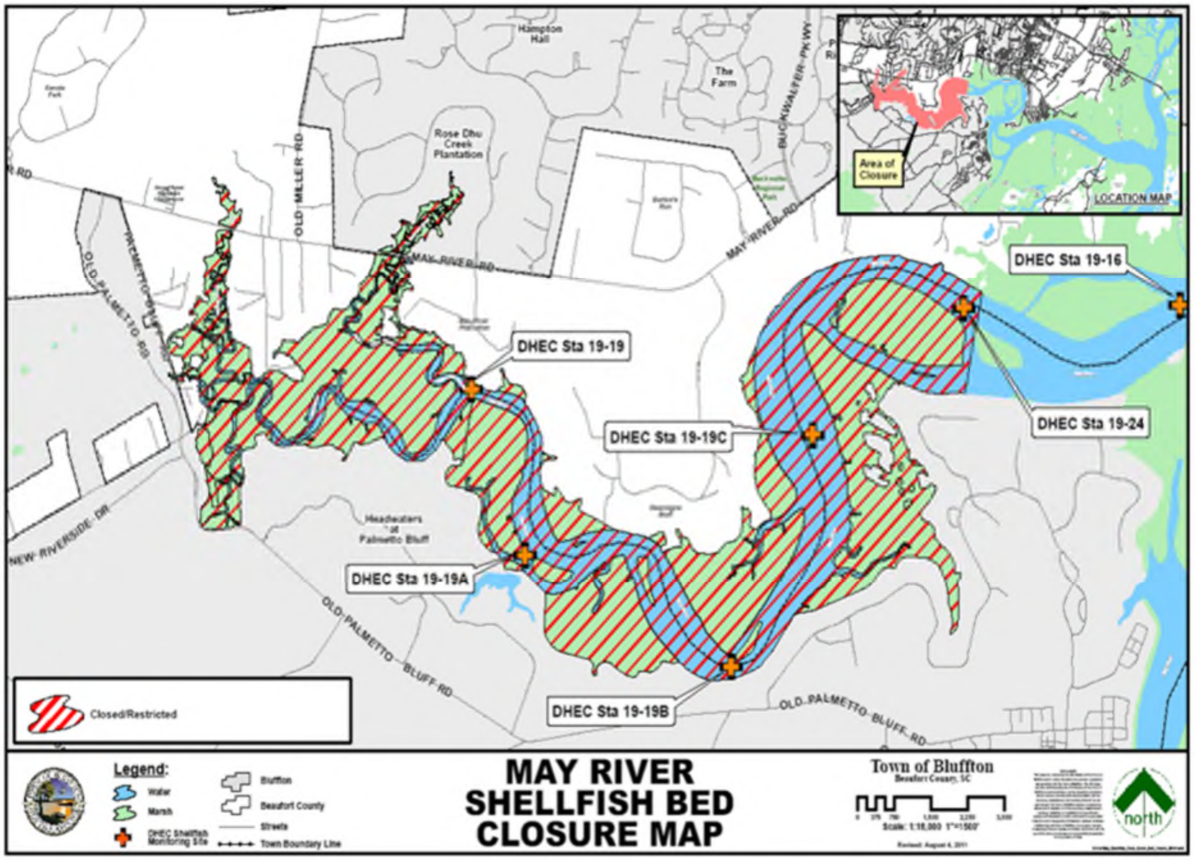

Figure 2. May River Shellfish Bed Closure Map

Through a weekly FC hotspot monitoring program focused in the Headwaters subwatersheds, comprised of the Duck Pond, Palmetto Bluff, Rose Dhu Creek, and Stoney Creek subwatersheds, the Town of Bluffton has identified areas of high FC concentration that contribute to pollutant loading within the May River. The indications from those efforts, as well as prior studies (Sanger et al., 2015; Montie, 2019), are that increased stormwater runoff volume from development is a key contributor to both stormwater volume and pollutant loading downstream, and that the Headwaters of the May River are particularly sensitive to freshwater inputs (as measured by changes in salinity). Development within the Town saw a rapid increase in population from 794 residents in 1990 to 12,530 people in 2010 and an estimated 25,557 people in 2019 (US Census Bureau, 2020). The resulting changes in land use over this time period saw an increase in impervious surfaces in the Headwaters from 5.78% in 2002 to 15.31% in 2018 (as summarized in Table 1). The Rose Dhu Creek and Stoney Creek basins are the most impervious at 19.74% and 15.49%, respectively.

Table 1: Change in Impervious Area in May River Headwaters

Subwatershed	Total Area (Acres)	2002 Impervious*		2018 Impervious*	
		Acres	%	Acres	%
Duck Pond	683.10	18.90	2.77%	18.90	2.77%
Palmetto Bluff	1,925.53	117.24	6.09%	186.24	9.67%
Rose Dhu Creek	4,168.06	342.00	8.21%	822.60	19.74%
Stoney Creek	5,480.16	229.79	4.19%	848.71	15.49%
TOTAL	12,256.85	707.93	5.78%	1,876.44	15.31%

*calculated from Town of Bluffton GIS files and referencing historic aerial imagery

The Town in partnership with a consultant team, stakeholders, and Beaufort County undertook a year-long planning effort to develop the May River Watershed Action Plan (Action Plan; AMEC et. al., 2011) to restore and protect shellfish harvesting throughout the length of the May River. The Action Plan lists multiple strategies and project recommendations, primarily stormwater pond modifications or construction, to achieve these goals. The Town's priority has been to implement Action Plan projects and refine Action Plan as a "living document" to reflect the current state of knowledge about stormwater treatment practices and policies to reduce FC. Since its 2011 adoption as a supporting document to the Town's Comprehensive Plan, watershed conditions, state of knowledge, and scientific evidence have advanced which necessitates an update of the Action Plan to reflect these current conditions.

The Town hired McCormick Taylor and Moffatt & Nichol (the Project Team) to develop watershed-water quality models for the four (4) May River Headwaters (Table 1) to support understanding of FC fate and transport in the Headwaters subwatersheds to develop strategies ultimately intended to open all shellfish stations to harvesting. In order to capture the variety of storm events, baseflow conditions, long-term trends, and variability in pollutant generation, transport, and fate, the Project Team developed a continuous simulation of both water quantity and quality within the XPSWMM environment.

1.2 Purpose of This Document

The purpose of this Water Quality (WQ) Modeling Report is to:

1. Provide the Town a summary of the data, processes, and assumptions the Project Team utilized to construct the XPSWMM water quality model,
2. Summarize the results (§2.0 Model Setup and §3.0 Model Calibration), and
3. Provide recommendations on policies, programs, projects, and potential strategic partnerships intended to restore and protect shellfish harvesting throughout the length of the May River as a substantial component of the May River Watershed Action Plan Update (Action Plan Update).

This report utilizes the significant amount of available information regarding the watershed and the May River itself, as well as lessons learned from previously implemented projects and policies within this watershed and similar watersheds. This document and the results of the model it describes will discuss changing land use conditions throughout the May River Watershed, state of knowledge surrounding FC in the environment, and the potential impact of BMPs to downstream water quality. The water quality model results have been prepared to estimate maximum FC concentrations (§4.1) and FC loads (§4.2) in order to identify hotspots.

Recommendations in this report include:

1. Detailing strategies to address current data gaps uncovered during the water quality model development and calibration (§3.0);
2. Establishing future monitoring to assess and calculate bacteria loading (§5.1);
3. Implementing projects, programs and policies that reflect the current state of knowledge regarding stormwater treatment (§5.2);
4. Evaluating the remaining proposed 2011 Action Plan projects for relevance under current conditions (§5.3); and
5. Proposing new projects, cost estimates, and ranking/prioritization of these projects to consider for inclusion in the Town's long-range CIP budget (§5.4).

1.3 Scope of Work

1.3.1 Develop Water Quality Models (Task 1)

The Project Team developed water quality models for the May River Headwaters subwatersheds of Rose Dhu Creek, Stoney Creek, Duck Pond, and Palmetto Bluff using XPSWMM (Version 2019.1.3). XPSWMM is a link-node network representation model, based on EPA SWMM 5, used to simulate hydrology, hydraulics, water quality, and surface flooding. For this project, XPSWMM's Runoff and Sanitary modes were utilized to model both hydrologic behavior and FC concentrations.

The models were developed to evaluate baseline (2002) and current (2018) land use conditions for FIB loading estimates pre- and post-shellfish harvesting impairment with the intent to reduce current loadings to pre-impairment levels. Calibration was based on field data provided by the Town and the calibrated models were applied to help determine the locations contributing to increases in fecal coliform and assess the potential impact of future Best Management Practices (BMPs) to reduce fecal coliform loadings to the May River. Model set up is described in Section 2.0 followed by a detailed description of the calibration process in Section 3.0 of this report.

The ultimate goal of the models is to provide a tool for Town staff to use to evaluate future development and BMP impacts to water quality and quantity.

Deliverables for Task 1 include:

- Completion of two May River watershed models, prioritizing the four (4) Headwaters subwatersheds for baseline (2002) and current (2018) land use conditions and BMP installation;
- Calibration of models based on field data from various sources (including the Town and USGS) to help determine what is responsible for increases in fecal coliform and potential impact of future BMPs to reduce fecal coliform loadings to the May River; and

- Delivery of the final models for staff use to evaluate future development and BMP impacts to water quality and quantity, as well as a summary report of assumptions made during model generation.

1.3.2 Evaluate Current Action Plan BMPs and Make Recommendations (Task 2)

Task 2 includes the evaluation of the current 2011 May River Watershed Action Plan's projects, as well as the state of the knowledge of best practices and policies implemented currently to address bacteria impairments in southeastern coastal regions.

Deliverables related to Task 2 include:

- Evaluation of the water quality monitoring data related to constructed BMPs' performance that has been recorded by the Town and stormwater industry.
- Identification and review of relevant research, regional case studies, etc. of fecal coliform reduction performance. This information will help the Project Team and Town evaluate if current practices, or other practices, such as changing outfall locations, policy changes, volume reduction, implementing green infrastructure, etc., would be suitable strategies to be included in the Action Plan Update.
- Evaluation of currently proposed projects in the 2011 Action Plan as they relate to the current state of knowledge related to fecal coliform reductions through stormwater BMPs. If current BMPs and/or locations are not in alignment with the water quality model outputs, the Project Team will propose new projects and locations for fecal reduction.
- Development of a GIS-based process for identifying new project locations. The process will be able to analyze existing Town of Bluffton geographic information (such as soils, stormwater drainage system assets, septic system/sanitary sewer system networks, property ownership, and FC hotspots) and flag new potential sites for BMPs that successfully address FC. This work also includes preparation of maps illustrating the potential properties to target for BMPs.
- Identification of data gaps that might limit the ability to complete Tasks 1 and 2 and steps to remediate those gaps.
- Development of cost estimates for approximately fifteen (15) proposed projects (based on preliminary sizing and planning-level costs) to inform the Town's long-term CIP funding needs.

2.0 Model Setup

To capture a variety of storm events, baseflow conditions, long-term trends, and variability in pollutant generation, transport, and fate, a continuous simulation of both water quantity and quality within the XPSWMM environment was developed. The stormwater management model (SWMM in XPSWMM) represents land areas as a series of subcatchments, with parameters that define retention and runoff of precipitation, infiltration, percolation to a shallow aquifer, and discharge from the aquifer. Subcatchments are connected to the drainage network, which may include natural watercourses, open channels, culverts and storm drainage pipes, storage and treatment units, outlets, diversions, and other elements of a drainage system. Nodes and links are used in XPSWMM to define the connectivity and control within the drainage network. Precipitation and other meteorological inputs are used to drive the hydrologic and water quality response in the simulation. Subcatchment runoff is directed to nodes within the link/node network, then transported throughout the network via model links.

The Town provided the Project Team with existing watershed delineations (for each of the four May River Headwaters subwatersheds), as well as several existing XPSWMM models. The existing models were short-term, event-based hydrologic & hydraulic simulations with no water quality component. Simulation times range from 24 hours to several days (i.e. they are not long-term/continuous models). These models included multiple versions of both the Stoney Creek and Duck Pond subwatersheds. There was no accompanying documentation that identified data sources or model setup procedures used for the existing models. As a result, it would have proven difficult to significantly draw on these models as a starting point beyond determining subcatchment delineations and confirming channel networks locations and cross-sections for the Project Team's continuous simulation water quality models developed as part of this scope of work effort. The following sections document and describe the procedures and model assumptions the Project Team followed to refine the watershed delineations and define the channel network, impervious cover, land use, meteorological data, infiltration, existing BMPs, and subcatchment parameters: area, width, slope, and impervious percentage.

Table 2: Summary of Data Compiled to Create Baseline and Current Conditions

Data Source	2002 Baseline Condition	2018 Current Condition
Watershed delineation*	Provided by Town	
Channel network*	GIS file: "drainage_7-16-15" and refinements with "LevelDEM79_40"	
Impervious area	Aerial imagery from 2002, GIS impervious file from Town	Aerial imagery from 2018, GIS impervious file from Town
Land use	2001 NLCD (National Land Cover Database)	2016 NLCD
Meteorological data	2002 KSAV Savannah Municipal Airport precipitation Calculated Daily PET (Potential Evapotranspiration) (Hamon method)	2018 KSAV Savannah Municipal Airport precipitation Calculated Daily PET (Hamon method)
Subcatchment parameters	Manning's n roughness coefficient for pervious land use	
Infiltration*	Minimum and maximum infiltration rates based on NRCS (Natural Resources Conservation Service) Soil Survey	
Groundwater*	USDA Web Soil Survey, USGS geologic & groundwater data, and professional judgment	
Water quality*	Fecal Coliform Event Mean Concentrations (EMCs) based on Land Use	
*Model parameter is identical for 2002 and 2018 conditions		

2.1 Watershed Delineation

The terminology the Project Team used to describe the various levels of watersheds (Figure 4) in the model are as follows: the May River **Watershed** is the entire drainage area of May River discharging to its confluence with Calibogue Sound (purple outline in Figure 2). **Subwatersheds** are the individual drainage areas for the May River that include the four Headwaters basins as shown in Figure 2: Rose Dhu Creek, Stoney Creek, Duck Pond, and Palmetto Bluff. **Subcatchments** represent a unique drainage area to a point (summarized in Table 3, and illustrated in Figure 3 for Stoney Creek, Figure 4 for Rose Dhu Creek, and Figure 6 for Duck Pond and Palmetto Bluff). Subcatchments were received from the Town and utilized in model construction. In some cases, where multiple subcatchments drained to a single point, subcatchment areas were combined to simplify modeling efforts. Additional procedures for development of model subcatchments is discussed in the Channel Network section below. Table 3 summarizes the subwatershed and subcatchment information.

Table 3: Watershed Delineation Information

Subwatershed	Total Area (acres)	Number of Subcatchments	Subcatchment Area (acres)		
			Average	Min	Max
Duck Pond	683.10	7	97.6	19.1	239.1
Palmetto Bluff	1,925.53	28	68.8	4.3	190.5
Rose Dhu Creek	4,168.06	26	160.3	9.1	465.6
Stoney Creek	5,480.16	62	88.4	3.8	593.3
TOTAL	12,256.85	123			

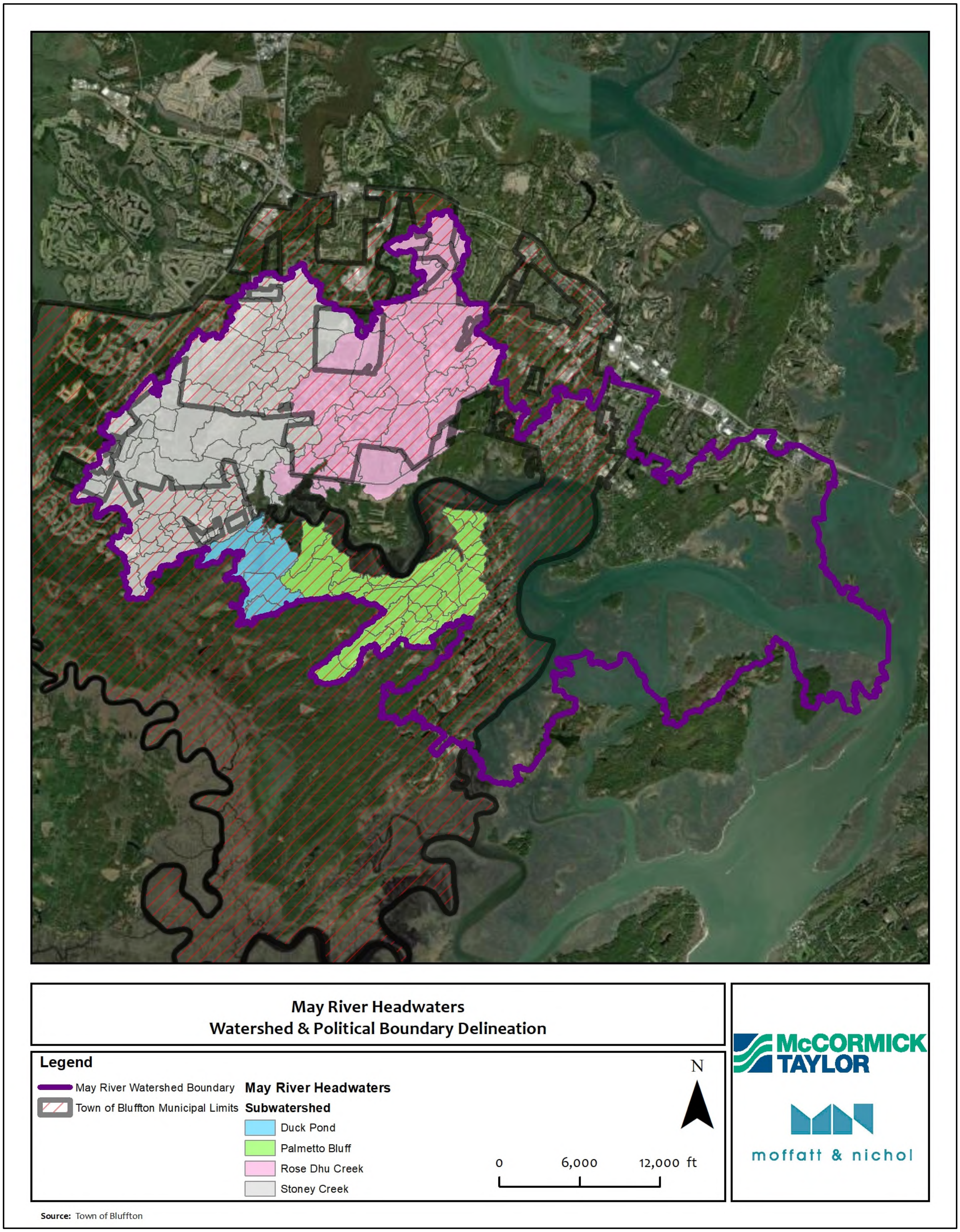

Figure 3. The May River Watershed and Headwaters

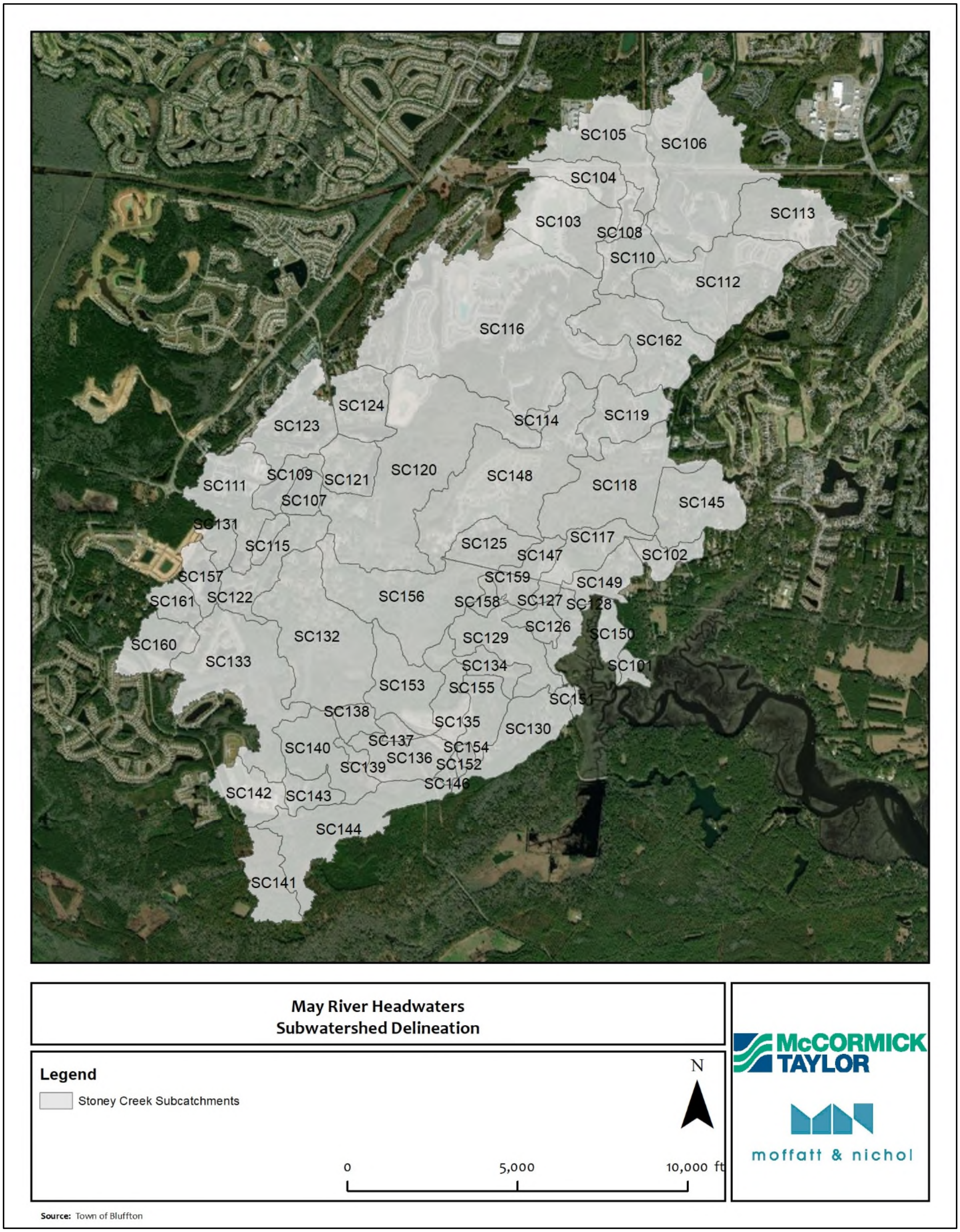

Figure 4. Stoney Creek Subwatershed and Subcatchments

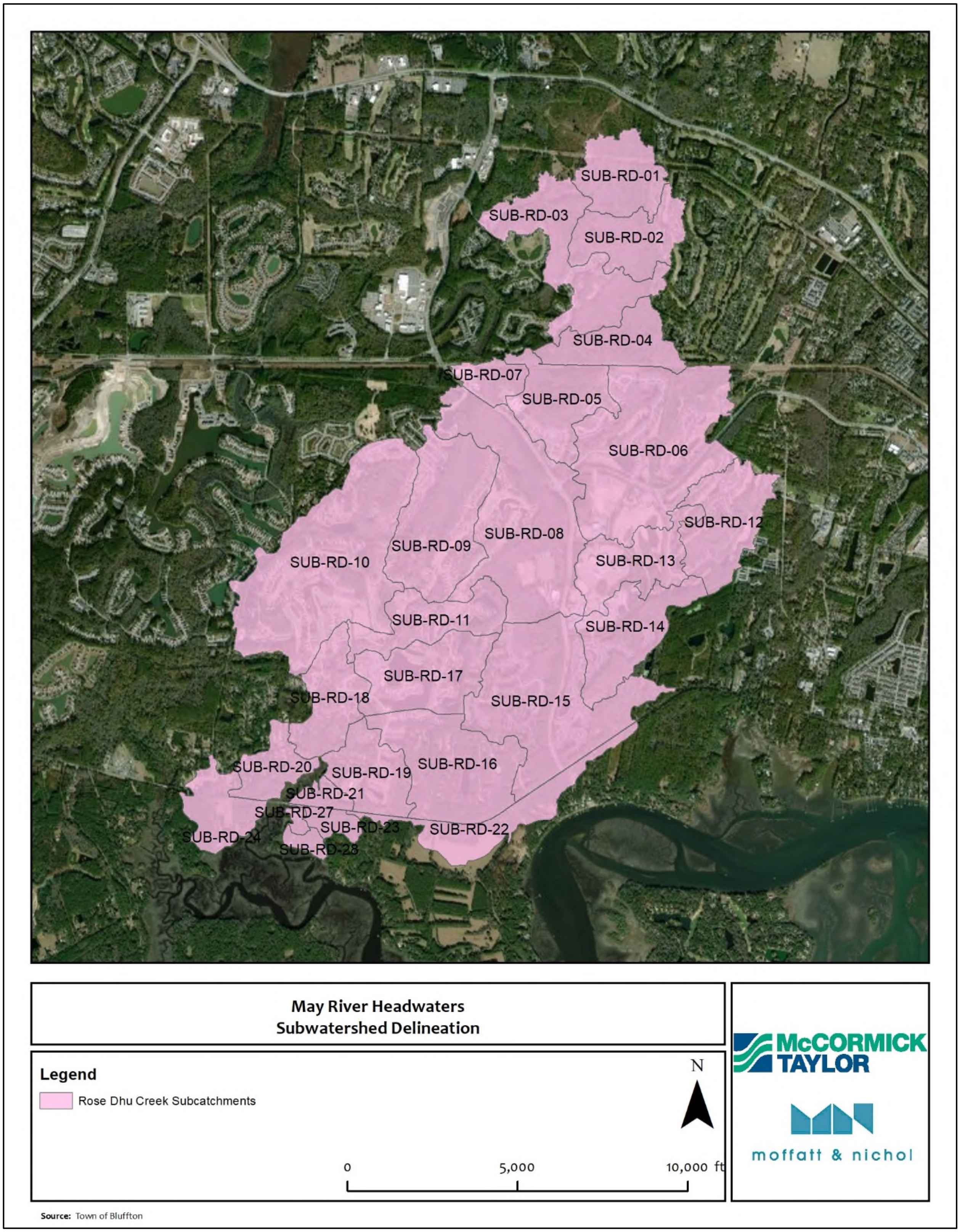

Figure 5. Rose Dhu Creek Subwatershed and Subcatchments

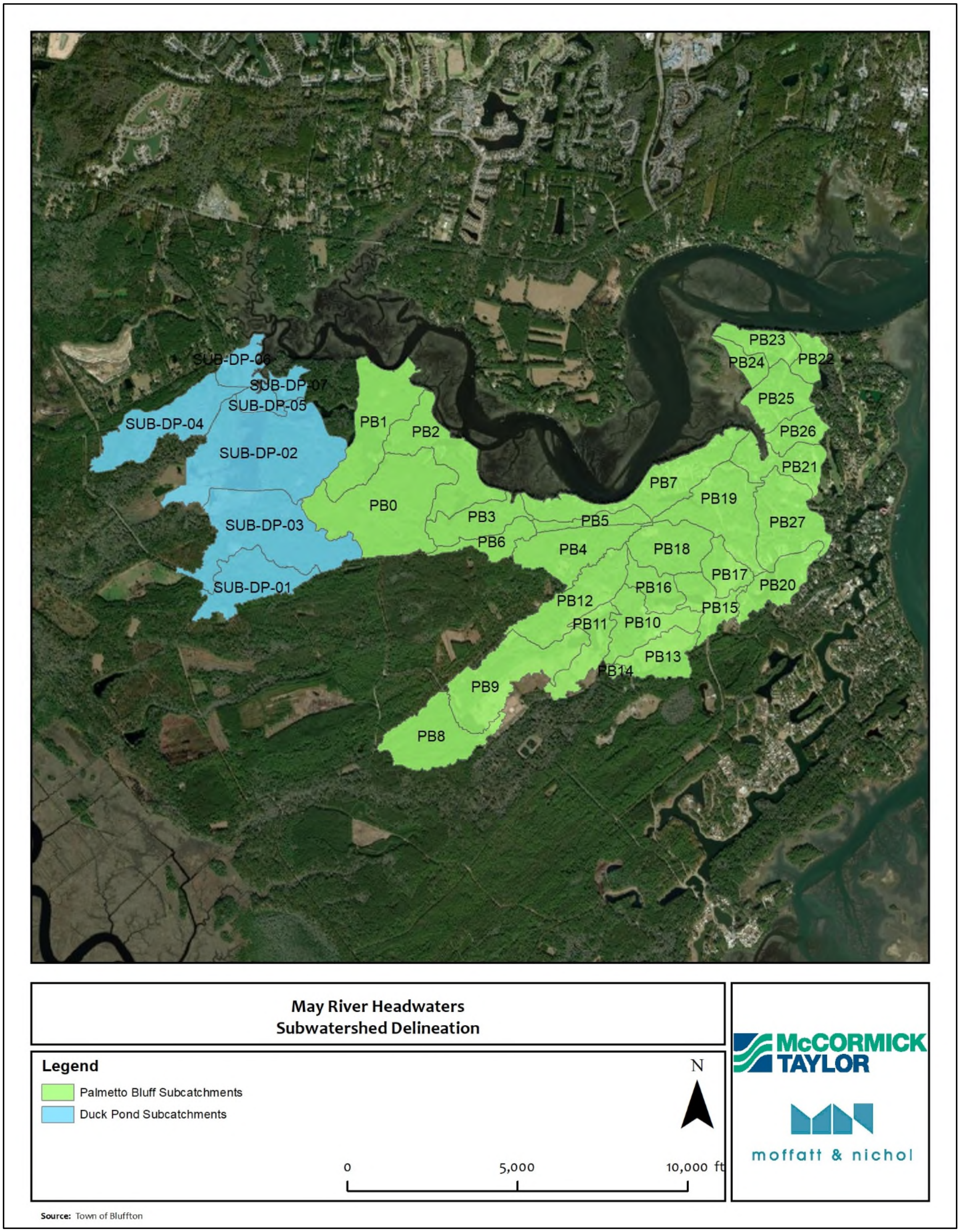

Figure 6. Duck Pond and Palmetto Bluff Subwatersheds and Subcatchments

2.2 Channel Network

Existing XPSWMM models for the Stoney Creek and Duck Pond subwatersheds were provided by the Town. These models contain cross section information including channel invert elevations and roughness coefficients for the channel network within each subwatershed. The previous existing hydraulic setup for Stoney Creek and Duck Pond was reviewed prior to use and a few modifications were made. Existing models for the Rose Dhu Creek and Palmetto Bluff subwatersheds were not available to the project teams in the early part of the project; therefore, the channel network and other model components were developed using provided data.

A balance was desired between maintaining an appropriate level of detail to adequately assess water quality concerns and minimizing the effort needed to construct model elements from scratch. Available data included delineated subwatershed and subcatchment boundaries, topography (including a 5x5 ft raster and 1-foot contours), impervious data, and National Land Cover Database (NLCD) land use datasets (further discussed in the Land Use section). Hydrologic parameters including area, land use, soil type, and infiltration loss rates were identified using available data. Hydraulic flow routing downstream from hydrologic points of concentration was more difficult to estimate as existing datasets do not contain cross section data. In order to limit the number of channel cross sections and characteristics that needed to be approximated, existing delineated subcatchments that drain to a common point were combined in some cases.

The drainage network for each subwatershed was determined using the 'drainage.shp' shapefile—the complete inventory of drainage features received in pieces from the Town and compiled by the Project Team—as a starting point. This file does not contain surveyed data for the channels (e.g. invert elevations, cross-section dimensions, or descriptions of the channel lining), but rather gave general descriptions of type (pipe or channel) and provided geographic location. Small, local drainage pipes and channels were filtered out to create a refined network containing only the major drainage conveyances necessary to provide connectivity between subcatchments and to the May River. Minor modifications to the channel flow paths were made in order to ensure that they align with the channel paths shown in the raster as described below:

Channel dimensions were approximated using the 'LevelDEM79_40' raster (provided by the Town), assuming a trapezoidal channel shape and estimating the top of bank location where the channel meets the surrounding floodplain (see Figure 7 below). A single channel cross section was determined for each subcatchment unless significant variation in cross section occurred within the subcatchment, in which case the channel was broken up to accommodate multiple channel cross sections.

Channel invert elevations were identified from the raster but adjusted as needed, as the bottom elevations shown in the raster appear to be approximate due to the 5x5 feet resolution (i.e. if the channel bottom width is less than 5 feet, the raster likely does not represent the lowest bottom elevation).

Channel roughness coefficients were assigned using the NLCD land use dataset, aerial imagery, and engineering judgment using Chow's suggested Manning's n values (provided in Table 4 below).

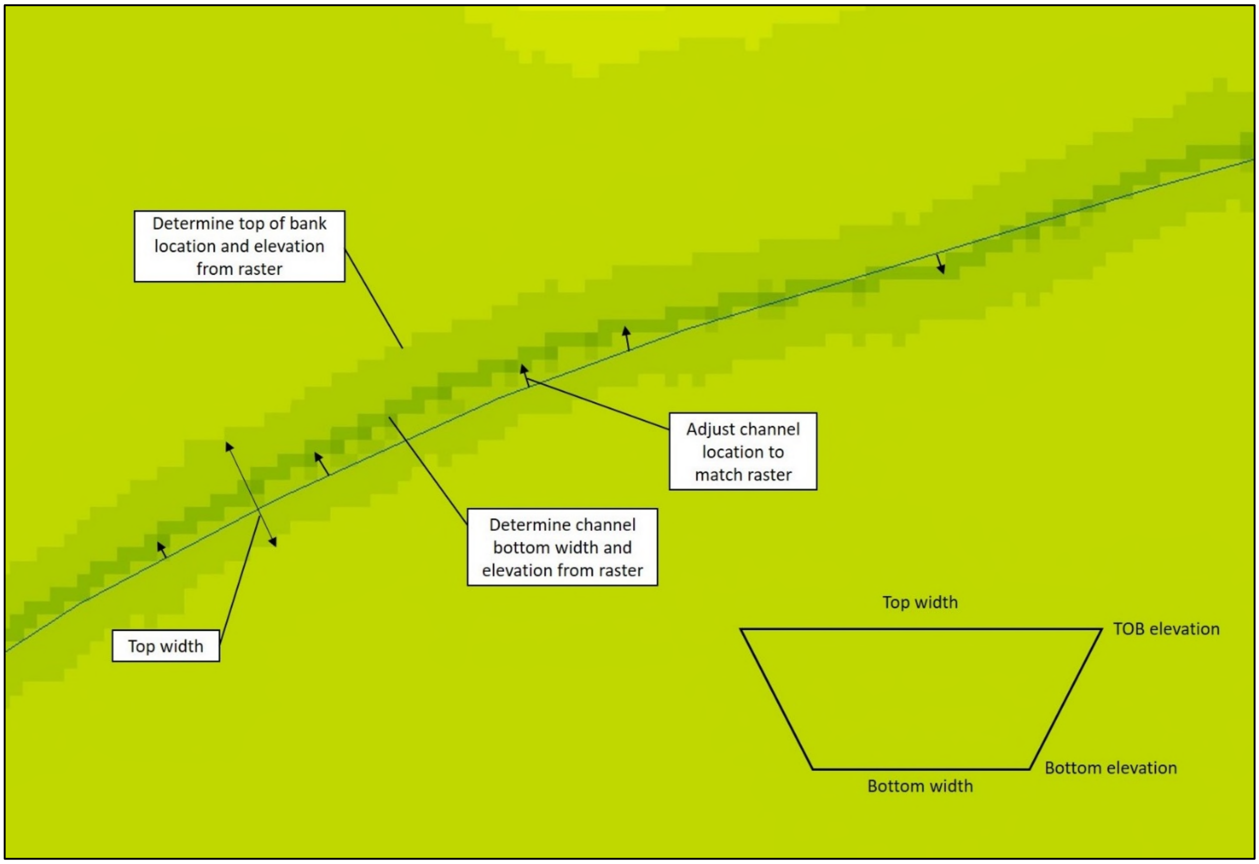

Figure 7. Channel cross section methodology

Table 4:. Chow's suggested Manning's n roughness coefficients

Type of Channel and Description	Minimum	Normal	Maximum
Natural streams - minor streams (top width at flood stage < 100 ft)			
1. Main Channels			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. same as above, but more stones and weeds	0.030	0.035	0.040
c. clean, winding, some pools and shoals	0.033	0.040	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.050
e. same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. same as "d" with more stones	0.045	0.050	0.060
g. sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150

Type of Channel and Description	Minimum	Normal	Maximum
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
a. bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
b. bottom: cobbles with large boulders	0.040	0.050	0.070
3. Floodplains			
a. Pasture, no brush			
1.short grass	0.025	0.030	0.035
2. high grass	0.030	0.035	0.050
b. Cultivated areas			
1. no crop	0.020	0.030	0.040
2. mature row crops	0.025	0.035	0.045
3. mature field crops	0.030	0.040	0.050
c. Brush			
1. scattered brush, heavy weeds	0.035	0.050	0.070
2. light brush and trees, in winter	0.035	0.050	0.060
3. light brush and trees, in summer	0.040	0.060	0.080
4. medium to dense brush, in winter	0.045	0.070	0.110
5. medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. dense willows, summer, straight	0.110	0.150	0.200
2. cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. same as 4. with flood stage reaching branches	0.100	0.120	0.160
4. Excavated or Dredged Channels			
a. Earth, straight, and uniform			
1. clean, recently completed	0.016	0.018	0.020
2. clean, after weathering	0.018	0.022	0.025
3. gravel, uniform section, clean	0.022	0.025	0.030
4. with short grass, few weeds	0.022	0.027	0.033
b. Earth winding and sluggish			
1. no vegetation	0.023	0.025	0.030
2. grass, some weeds	0.025	0.030	0.033
3. dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. earth bottom and rubble sides	0.028	0.030	0.035

Type of Channel and Description	Minimum	Normal	Maximum
5. stony bottom and weedy banks	0.025	0.035	0.040
6. cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged			
1. no vegetation	0.025	0.028	0.033
2. light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. smooth and uniform	0.025	0.035	0.040
2. jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. dense weeds, high as flow depth	0.050	0.080	0.120
2. clean bottom, brush on sides	0.040	0.050	0.080
3. same as above, highest stage of flow	0.045	0.070	0.110
4. dense brush, high stage	0.080	0.100	0.140

The network of nodes and links that was included in the May River Headwaters Watershed model are summarized in Table 5 and illustrated in Figure 8. Note that Stoney Creek and Palmetto Bluff have multiple subcatchments that have separate outfalls into the May River for the entire subwatershed. There are six nodes in Stoney Creek and nine nodes in Palmetto Bluff that are separate discharge points.

Table 5: Summary of Node and Link Information

Subwatershed	Number of Nodes	Number of Links
Duck Pond	8	7
Palmetto Bluff	39	30
Rose Dhu Creek	36	35
Stoney Creek	87	79
TOTAL	170	151

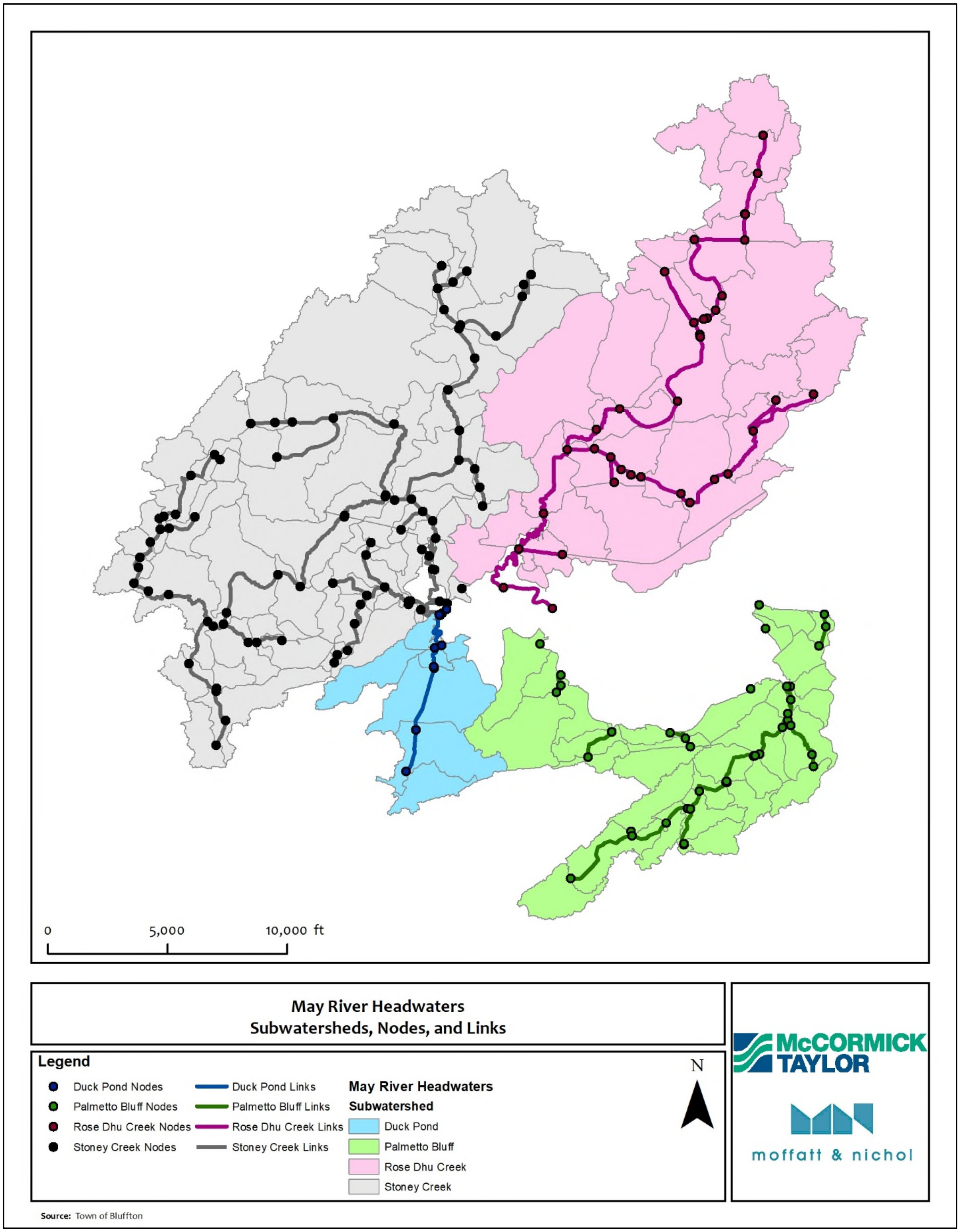

Figure 8. Subwatershed Node and Link Network for Model

2.3 Impervious Area

The Town provided impervious area (IA) data for 2018 that included building footprints, walkways/pathways, parking areas, driveways, roads, curbs, and ponds. A complete impervious dataset for 2018 was created by combining these shapefiles and checking for quality assurance using aerial imagery and land use data. Impervious data for 2002 was created by removing areas from the 2018 dataset, using historical aerial imagery and 2001 NLCD data to determine which areas were developed in 2002. Figures 9 and 10 illustrate the impervious area in each subcatchment as a percentage of total area for 2002 and 2018, respectively. Table 6 summarizes the subcatchments with the largest overall impervious area (acres) in 2018; Table 7 summarizes the subcatchments with the largest percentage of subcatchment area being impervious cover. Two subcatchments (SC112 and SUB-RD-13, highlighted in light grey within each Table) are included on both lists.

Table 6: 2018 Subcatchments with Largest Impervious Areas

Subcatchment	Total Area (acres)	Impervious Area (acres)	Impervious Area (%)
SC116	741.45	**163.72**	22%
SUB-RD-10	465.59	**105.56**	23%
SUB-RD-06	411.01	**100.14**	24%
SUB-RD-15	352.73	**87.68**	25%
SUB-RD-17	292.79	**76.46**	26%
SUB-RD-08	384.14	**67.19**	17%
SC162	741.45	**59.92**	8%
SC112	201.66	**58.95**	29%
SC106	260.56	**54.48**	21%
SUB-RD-13	133.88	**53.49**	40%

Table 7: 2018 Highest Percent Impervious Subcatchments

Subcatchment	Total Area (acres)	Impervious Area (acres)	Impervious Area (%)
SC110	56.46	37.11	66%
SUB-RD-13	133.88	53.49	40%
SC142	60.72	23.58	39%
SC119	84.22	27.55	33%
SC111	104.78	32.07	31%
SC124	64.47	19.39	30%
SC157	35.94	10.65	30%
SC143	33.46	9.79	29%
SC112	201.66	58.95	29%
SC123	103.57	29.52	29%

Throughout the entire May River Headwaters, the IA has been classified into four different groups based on ranges of impervious area (as shown in Figure 9 and Figure 10), and summarized in Table 8. In 2002 the majority (78%) of the subcatchments had less than 10% impervious area, and about 5% in the most impacted category. In 2018, development has increased such that almost one-third of all subcatchments in the May River Headwaters would have physical, chemical, and ecological impacts as a result of impervious area.

Table 8: Subcatchment Classification by Percent Impervious Area

Impervious Area (%)	Water Quality Concern*	Number of Subcatchments (2002)	Number of Subcatchments (2018)
0-10	Sensitive	97	62
10-20	Physical and Chemical Impacts	19	28
20-30	Ecological Process Impacts	7	26
>30		0	7
Total:		123	123
*based on thresholds from Sanger et al., 2015			

In XPSWMM, each subcatchment is divided into three areas: **pervious area**, **connected impervious area**, and **disconnected impervious area**. Both the pervious area and connected impervious area are directed to the subcatchment outlet, while the disconnected impervious area is directed to the pervious area before being routed to the outlet. The proportion of impervious area with runoff directed to pervious areas (i.e., disconnected impervious area) versus impervious area directly connected to the storm drainage system (directly connected impervious area) for each subcatchment was estimated using the breakdown of land use types. The proportion of disconnection is not explicitly known but can be estimated and can also be a calibration parameter. The percentage of impervious area that is disconnected versus connected was estimated for each land use type using guidance from the literature on estimating disconnection fractions (e.g., Sutherland, 2000) and professional modeling judgement (Table 9). The amount of connected impervious area is calculated as the total impervious area minus the disconnected impervious area.

Table 9: Estimated Disconnected Impervious Area for Land Use Classifications

Land Use	Percent Disconnected
Developed Open Space	80%
Developed Low Intensity	75%
Developed Medium Intensity	40%
Developed High Intensity	25%
Forest	100%
Shrubland, Grassland, Pasture, & Barren Land	100%
Wetlands	100%
Cultivated Cropland	100%

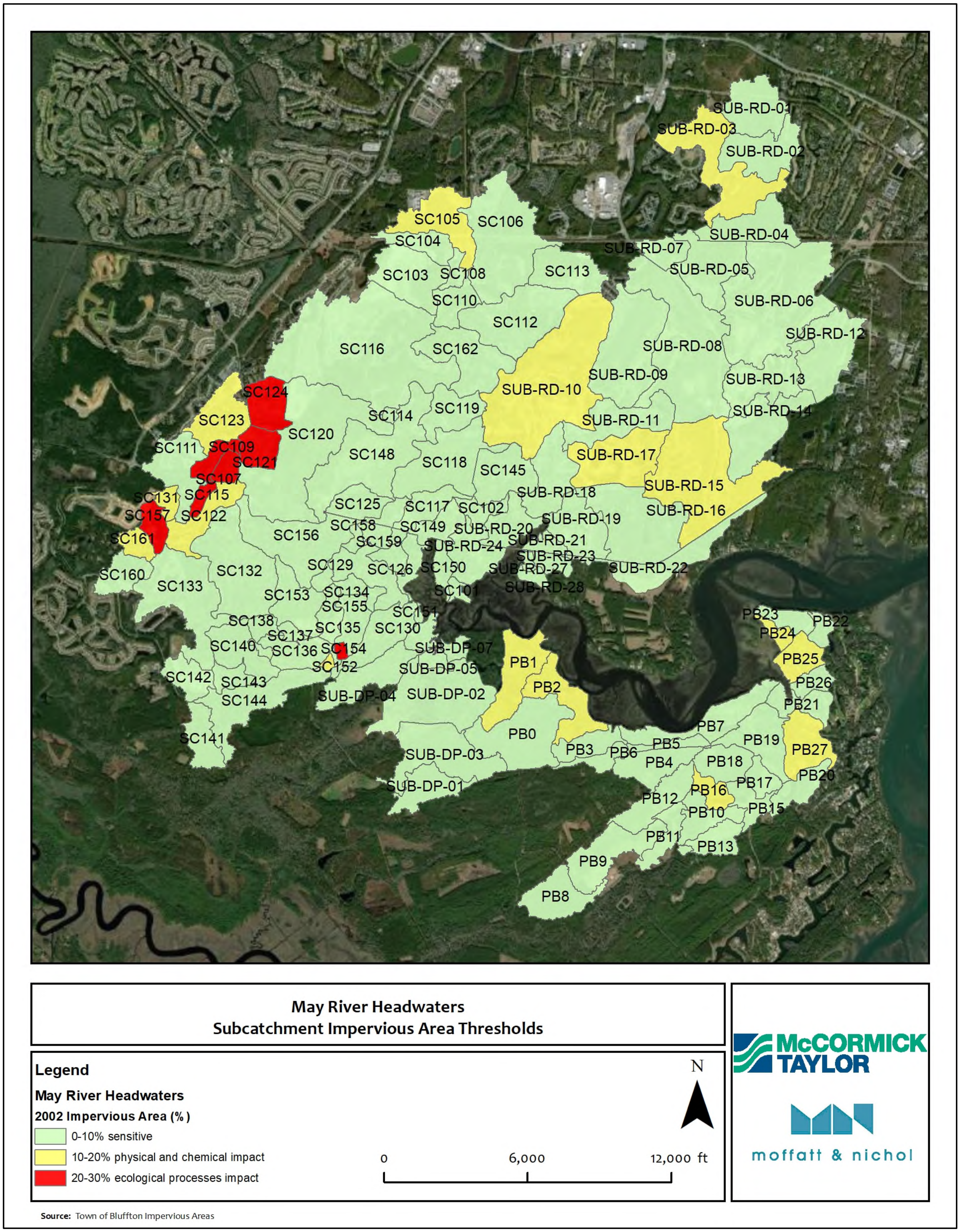

Figure 9. 2002 Impervious Area as Percent of Subcatchment Area

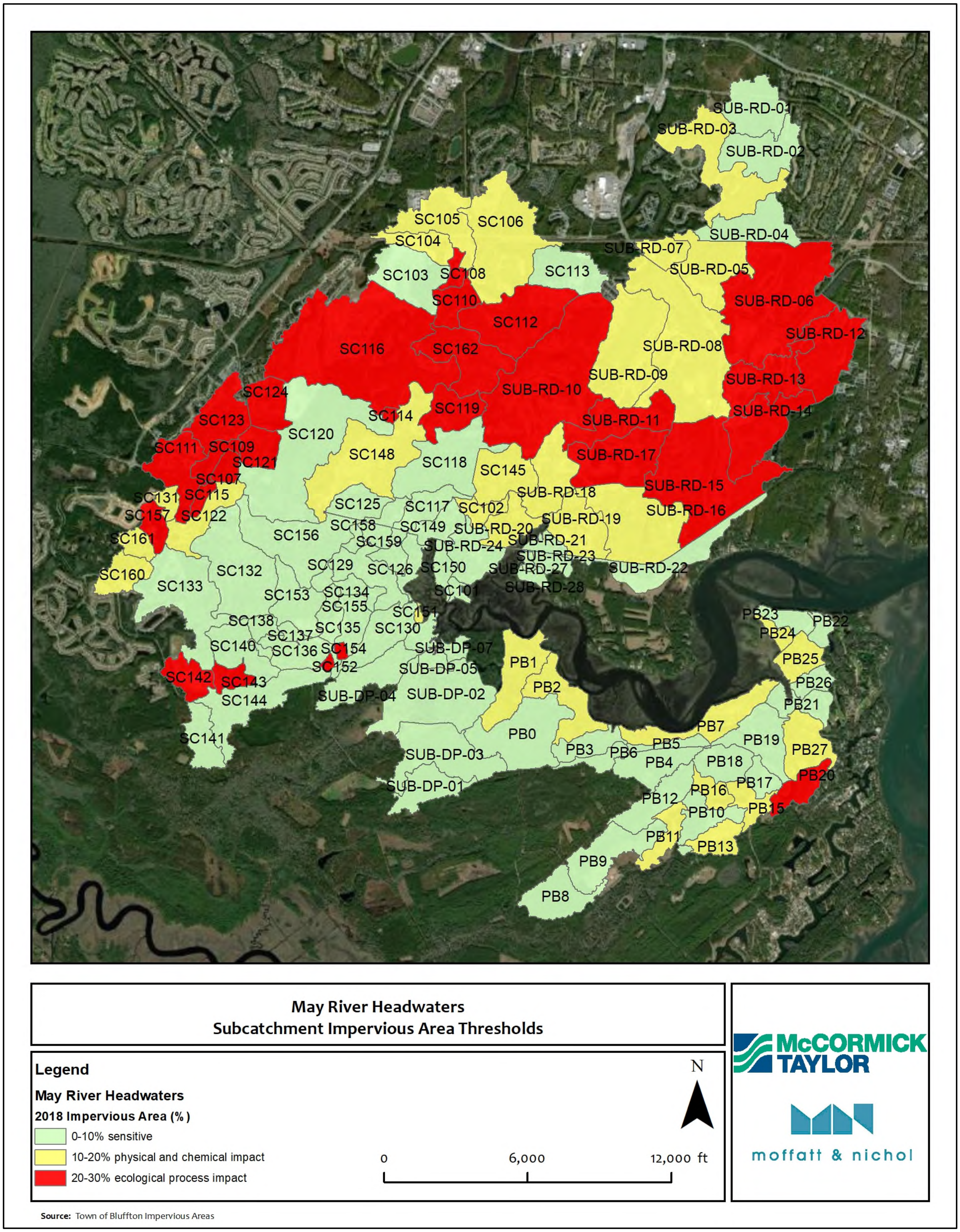

Figure 10. 2018 Impervious Area as Percent of Subcatchment Area

2.4 Land Use

Subcatchment hydrology is driven by land cover (impervious versus pervious surfaces), and pollutant generation and runoff are related to land use (e.g., commercial, residential, or natural) to a large extent. For example, each land use will have specific pollutant build-up and wash-off parameters. Both land use and land cover are defined within each subcatchment. Land use is assigned to subcatchments on a percentage basis.

The Town provided 2018 land use data; however, this data was a mixture of zoning and land use which made it difficult to determine what was on the ground. Also, comparable data was not readily available for 2002. Therefore, the National Land Cover Database (NLCD), developed by the Multi-Resolution Land Characteristics Consortium of US Geological Survey (USGS) and additional federal agencies, was used for both the 2002 and 2018 periods to provide a consistent basis upon which to develop baseline and current condition land use and land cover. Based on 30-meter Landsat imagery, NLCD data is available in seven different "epochs," including 2001 and 2016. The 2001 NLCD dataset was used to represent 2002 land use, and the 2016 NLCD dataset (the most current epoch available) was used to represent 2018 land use. The 2016 data was compared with the impervious data provided by the Town and it was determined that this would be the best available data to use. NOAA Coastal Change Analysis Program (C-CAP) data was also reviewed and compared to the NLCD data. The Project Team determined that smaller roadways were not included in the C-CAP data and therefore in the more residential areas, the NLCD data would provide the most accurate data. Table 10 summarizes the NLCD land cover classifications and descriptions. Maps (Figures 11 and 12) showing the NLCD datasets for 2001 and 2016 are provided in the sections 2.4.1 and 2.4.2 below.

There are two limitations related to use of NLCD for this model. First is the misalignment of time periods. Though the degree to which some development was not accounted for depends on how much occurred in each intervening period (e.g. how much development occurred between 2016 and 2018). However, the Team was able to address this concern in calibration (§3.2). The other issue is that it would have been better to use a combination of locally derived land use using parcel data combined with remote sensing sources like NLCD. That requires a robust starting dataset, which was not available, and an extensive amount of work (which was not feasible with the time or budget).

Table 10: NLCD Land Cover Classifications and Descriptions

Class\ Value	Classification Description
Water	
11	Open Water- areas of open water, generally with less than 25% cover of vegetation or soil.
12	Perennial Ice/Snow- areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
Developed	
21	Developed, Open Space- areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	Developed, Low Intensity- areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
23	Developed, Medium Intensity -areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
24	Developed High Intensity-highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
Barren	
31	Barren Land (Rock/Sand/Clay) - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Forest	
41	Deciduous Forest- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
42	Evergreen Forest- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
43	Mixed Forest- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.

Class\ Value	Classification Description
Shrubland	
51	Dwarf Scrub- Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
52	Shrub/Scrub- areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
Herbaceous	
71	Grassland/Herbaceous- areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling but can be utilized for grazing.
72	Sedge/Herbaceous- Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.
73	Lichens- Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.
74	Moss- Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.
Planted/Cultivated	
81	Pasture/Hay-areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
82	Cultivated Crops -areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
Wetlands	
90	Woody Wetlands- areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
95	Emergent Herbaceous Wetlands- Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

2.4.1 2002 Baseline Land Use Condition

Table 11 summarizes the land cover/land use for the entire Headwaters region in 2002, and Figure 11 illustrates the spatial locations of these classifications. In the baseline condition, the predominant land covers in the Headwaters of the May River Headwaters were evergreen forest (35.55%) and woody wetlands (33.35%). The total amount of developed lands, the areas classified as "Developed Open Space and Low, Medium, and High Intensity" (highlighted in grey in Tables 11 – 14), amounted to 1,307.44 acres (10.67%).

Table 11: May River Headwaters Overall 2002 Baseline Land Use Condition

Land Cover	Land Use Code	Area (acres)	Percentage
Open Water	11	264.94	2.16%
Developed, Open Space	21	1,132.48	9.24%
Developed, Low Intensity	22	138.78	1.13%
Developed, Medium Intensity	23	33.01	0.27%
Developed, High Intensity	24	3.17	0.03%
Barren Land	31	13.37	0.11%
Deciduous Forest	41	66.50	0.54%
Evergreen Forest	42	4,356.95	35.55%
Mixed Forest	43	282.47	2.30%
Shrub/Scrub	52	461.25	3.76%
Herbaceous Grassland	71	1,131.36	9.23%
Hay/Pasture	81	111.64	0.91%
Cultivated Crops	82	25.77	0.21%
Woody Wetlands	90	4,087.70	33.35%
Emergent Herbaceous Wetlands	95	147.46	1.20%

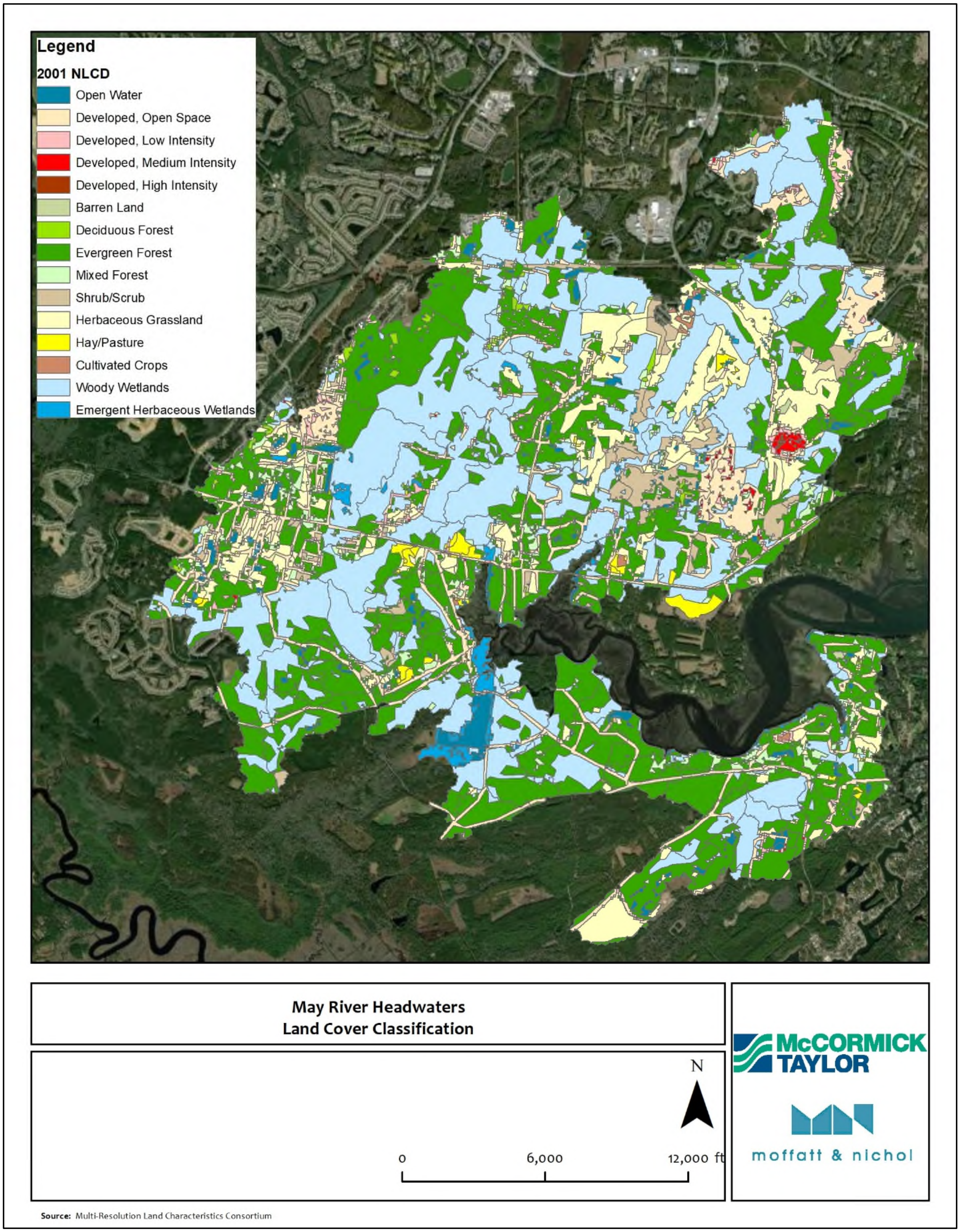

Figure 11. Baseline Land Cover in May River Headwaters

Table 12 summarizes the land cover/land use by subwatershed in 2002. The predominant land covers are evergreen forest and woody wetlands for all four of the subwatersheds. The amount of development in the baseline condition for each subwatershed, from least to greatest amount, is Duck Pond (9.13%); Stoney Creek (9.63%); Palmetto Bluff (9.66%); and Rose Dhu Creek (12.75%).

Table 12: May River Headwater Subwatersheds 2002 Baseline Land Use Condition

Land Cover/Land Use	Land Use Code	Duck Pond (acres)	Palmetto Bluff (acres)	Rose Dhu Creek (acres)	Stoney Creek (acres)
Open Water	11	64.10	52.24	46.92	101.67
Developed, Open Space	21	59.00	172.54	441.36	459.57
Developed, Low Intensity	22	3.36	12.57	57.32	65.54
Developed, Medium Intensity	23	0.00	0.67	29.64	2.71
Developed, High Intensity	24	0.00	0.22	2.95	0.00
Barren Land	31	0.00	4.65	7.08	1.64
Deciduous Forest	41	0.00	0.97	22.65	42.87
Evergreen Forest	42	204.57	1,092.85	1,103.61	1,955.91
Mixed Forest	43	1.32	64.85	69.33	146.98
Shrub/Scrub	52	0.49	10.43	327.71	122.62
Herbaceous Grassland	71	2.28	155.23	630.55	343.30
Hay/Pasture	81	0.00	6.40	50.21	55.03
Cultivated Crops	82	0.00	3.26	18.86	3.65
Woody Wetlands	90	275.19	339.74	1,337.36	2,135.41
Emergent Herbaceous Wetlands	95	72.80	8.92	22.50	43.25
Total Area		683.10	1,925.53	4,168.06	5,480.16

2.4.2 2018 Current Land Use Condition

In the 2018 current condition, the predominant land covers in the Headwaters of the May River were evergreen forest (25.71%) and woody wetlands (30.22%), as summarized in Table 13 and illustrated in Figure 12. The total amount of developed lands amounted to 3,765.46 acres (30.72%).

Table 13: May River Headwater Watersheds 2018 Current Land Use Condition

Land Cover/Land Use	Land Use Code	Area (acres)	Percentage
Open Water	11	347.93	2.84%
Developed, Open Space	21	2,180.14	17.79%
Developed, Low Intensity	22	1,134.82	9.26%
Developed, Medium Intensity	23	409.00	3.34%
Developed, High Intensity	24	41.49	0.34%
Barren Land	31	54.84	0.45%
Deciduous Forest	41	35.91	0.29%
Evergreen Forest	42	3,151.22	25.71%
Mixed Forest	43	270.49	2.21%
Shrub/Scrub	52	326.87	2.67%
Herbaceous Grassland	71	294.96	2.41%
Hay/Pasture	81	91.42	0.75%
Cultivated Crops	82	9.00	0.07%
Woody Wetlands	90	3,704.06	30.22%
Emergent Herbaceous Wetlands	95	204.70	1.67%

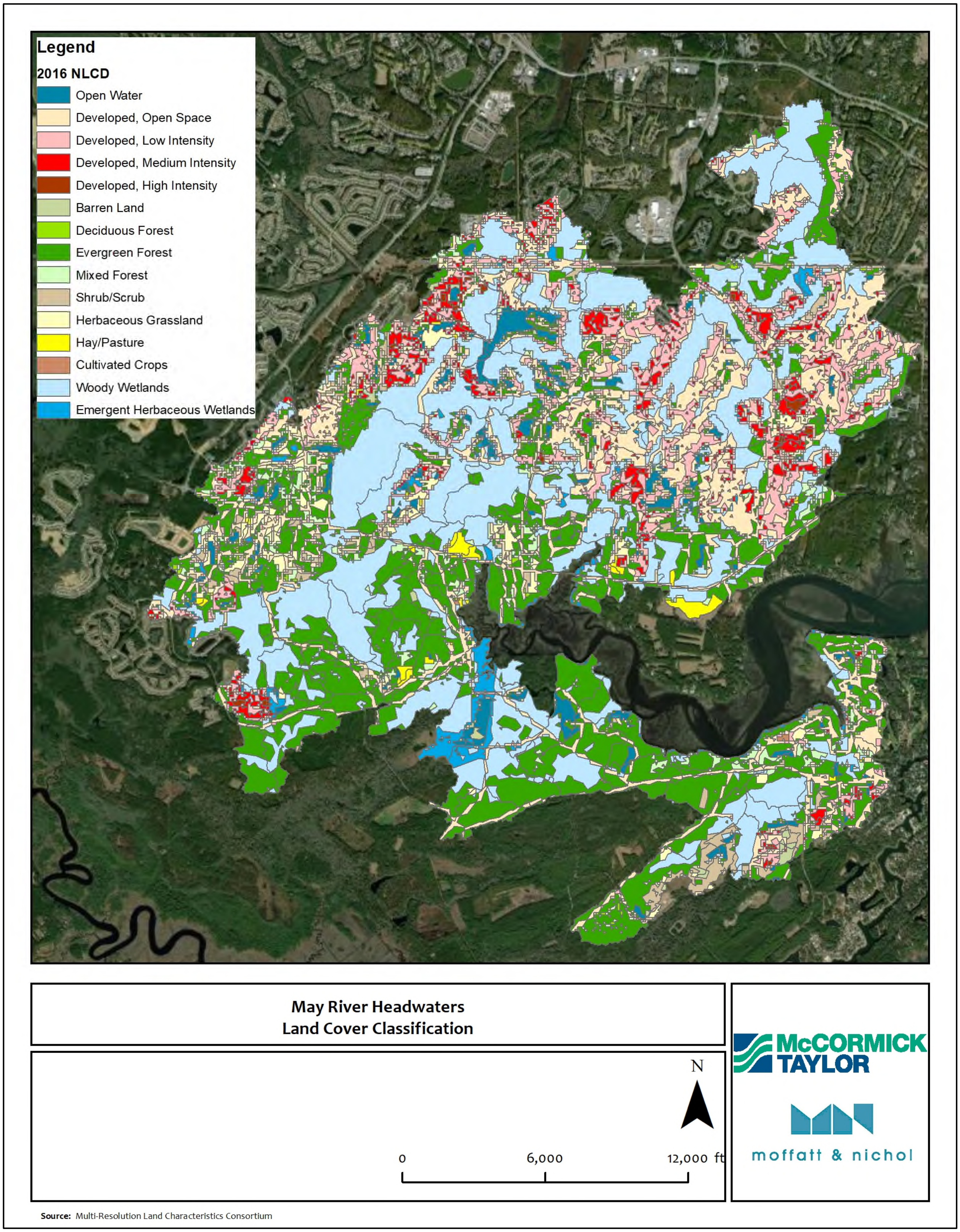

Figure 12. Current Condition Land Cover in May River Headwaters

Table 14 summarizes the current condition of land use/land cover by subwatershed. The predominant land covers are evergreen forest and woody wetlands for all the subwatersheds, except for Rose Dhu Creek where developed open space surpasses evergreen forest. The amount of development in each subwatershed, from least to greatest amount, is Duck Pond (8.85%); Palmetto Bluff (18.37%); Stoney Creek (25.01%); and Rose Dhu Creek (47.52%).

Table 14: May River Headwater Subwatersheds 2018 Current Land Use Condition

Land Cover/Land Use	Land Use Code	Duck Pond (acres)	Palmetto Bluff (acres)	Rose Dhu Creek (acres)	Stoney Creek (acres)
Open Water	11	32.49	72.80	63.10	179.54
Developed, Open Space	21	57.07	279.89	1092.11	751.07
Developed, Low Intensity	22	3.35	52.51	668.94	410.02
Developed, Medium Intensity	23	0.00	18.41	203.14	187.46
Developed, High Intensity	24	0.00	2.89	16.45	22.16
Barren Land	31	6.60	22.63	4.31	21.30
Deciduous Forest	41	0.00	5.93	11.44	18.53
Evergreen Forest	42	201.84	888.03	686.57	1374.78
Mixed Forest	43	1.13	63.72	53.98	151.65
Shrub/Scrub	52	0.75	125.64	72.01	128.48
Herbaceous Grassland	71	3.34	36.25	51.53	203.84
Hay/Pasture	81	0.00	3.44	38.98	48.99
Cultivated Crops	82	0.00	3.12	1.73	4.15
Woody Wetlands	90	280.28	337.00	1168.94	1917.85
Emergent Herbaceous Wetlands	95	96.26	13.25	34.84	60.35
Total Area		683.10	1925.53	4168.06	5480.16

2.4.3 Land Use Changes in the Headwaters of the May River

From 2002 to 2018, the developed area (areas classified as Developed Open Space and Low, Medium, and High Intensity) increased in all of the May River Headwaters subwatersheds except for Duck Pond. The percentage of forests and woody wetland areas decreased from 2002 to 2018 as a result of development. Note that the decrease in developed open space for the Duck Pond subwatershed may be related to increases in shrub/scrub or herbaceous grassland. Because developed open space (mostly turfgrass areas) is categorized as a type of development, the decrease in this category for Duck Pond does not mean that impervious surfaces like buildings or roads were removed.

Table 15: Changes in the May River Headwaters Land Use Condition

Land Cover/Land Use	Duck Pond	Palmetto Bluff	Rose Dhu Creek	Stoney Creek
Open Water	-49%	39%	34%	77%
Developed, Open Space	-3%	62%	147%	63%
Developed, Low Intensity	0%	318%	1067%	526%
Developed, Medium Intensity		2658%	585%	6819%
Developed, High Intensity		1200%	458%	
Barren Land		387%	-39%	1195%
Deciduous Forest		511%	-50%	-57%
Evergreen Forest	-1%	-19%	-38%	-30%
Mixed Forest	-14%	-2%	-22%	3%
Shrub/Scrub	54%	1105%	-78%	5%
Herbaceous Grassland	46%	-77%	-92%	-41%
Hay/Pasture		-46%	-22%	-11%
Cultivated Crops		-4%	-91%	14%
Woody Wetlands	2%	-1%	-13%	-10%
Emergent Herbaceous Wetlands	32%	49%	55%	40%

In addition to the NLCD land cover/land use breakdown, a distinction was made between developed land on septic versus sewer systems (as of 2018) using data provided by the Town, as illustrated in Figure 13. This information was used later as part of the water quality component of model development. The underlying assumption for the water quality model was developed areas that were not connected to sewer were utilizing septic systems. The Project Team later learned that some of this data was inaccurate. Specifically, many developed areas in Palmetto Bluff were not listed as being connected to sewer initially as sewer was extended following new phases of development. The XPSWMM model has been updated to reflect this, but Figure 12 shows the septic/sewer information as it was received from the Town. Further explanation of how the water quality parameters were assigned based on land use is discussed in Section 2.8.

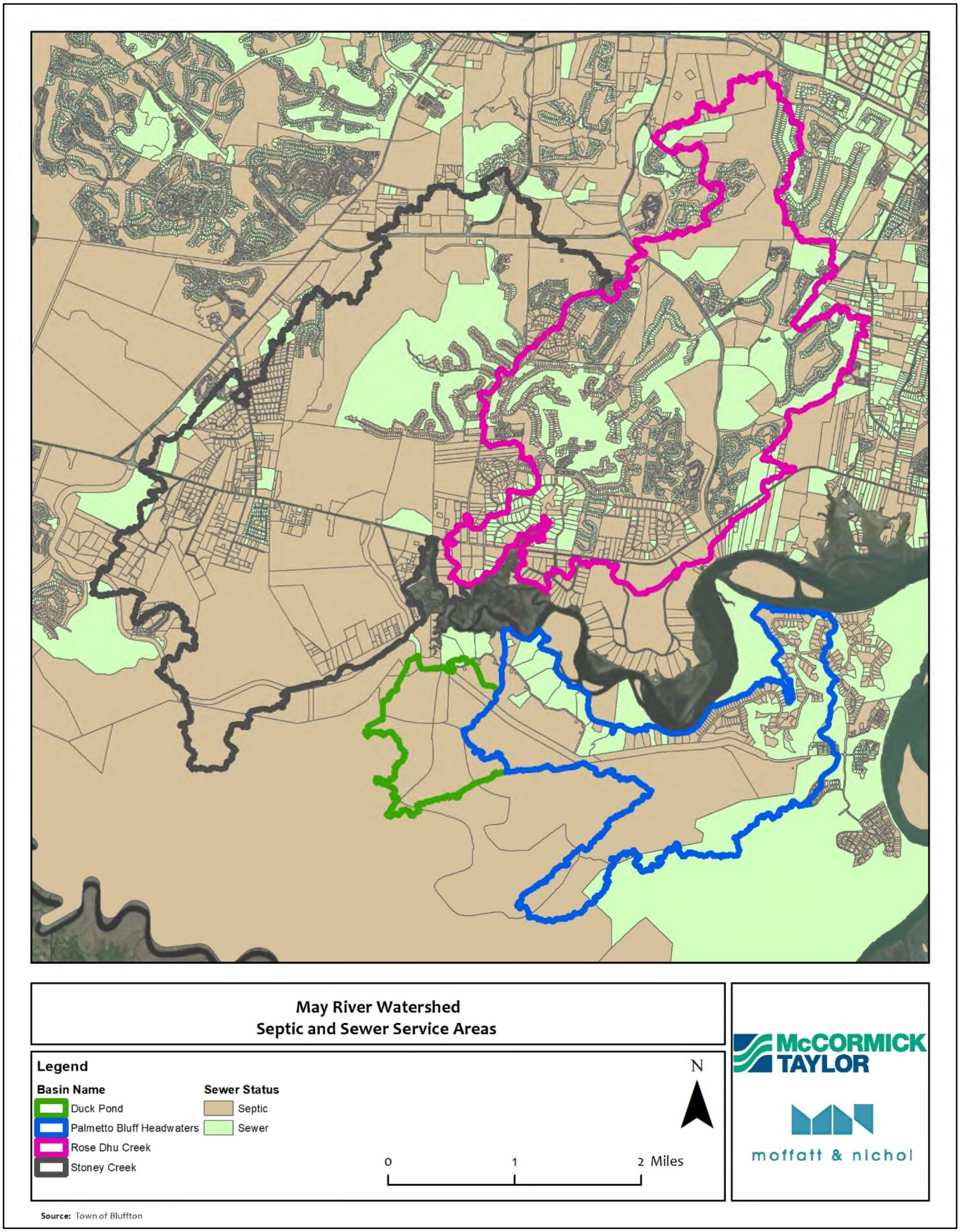

Figure 13. Areas with Sewer Service or Septic Systems in the May River Watershed

2.5 Meteorological Data

Simulation of hydrology and pollutant processes in the model are primarily driven by meteorological data, including rainfall and evaporation/evapotranspiration (ET). The ability of a model to predict hydrologic response and pollutant generation, fate, and transport is strongly affected by the accuracy and representation of meteorological data.

2.5.1 Precipitation

Complete precipitation time series were required for both the Baseline and Current model time periods. The Baseline model period runs from January 2000 through December 2004 and the Current model period runs from July 2015 until December 2018.

Precipitation data from 2000 through 2018 was retrieved from several stations in proximity to the study area (Table 16 and Figure 14) since there were no stations within the watershed that covered those complete time periods. While 15-minute precipitation data was desired for modeling, a complete record of 15-minute data was only available at the ACE Basin NERR monitoring station at Bennett's Point (ACEBPMET), which is approximately forty miles from the May River study area, and it is likely that the precipitation records at the ACEBPMET station vary considerably from stations closer to the study area. Therefore, a complete hourly precipitation record was created using data from the KSAV Savannah Municipal Airport station. Table 17 summarizes the total monthly precipitation for 2002 and 2018, as measured at KSAV.

Table 16: Availability of Precipitation Data

Station	Frequency	Time Period
USGS 02176735 May River	Daily	06/2002 - 06/2004
USGS 02197500 Savannah River	15 minute	09/2010 - 08/2019
USGS 021989784 Little Black River	15 minute	10/2007 - 10/2017
USGS 021989791 Little Back River	15 minute	10/2007 - 10/2017
USGS 0219897993 Savannah River	15 minute	08/2013 - 08/2019
COOP097847 Savannah GA International Airport	Hourly	01/2001 - 12/2013
KSAV Savannah Municipal Airport	Hourly	01/2000 - 08/2019
ACEBPMET	15 minute	03/2001 - 09/2019

*USGS 02197500 Savannah River not shown on map due to large distance from study area.

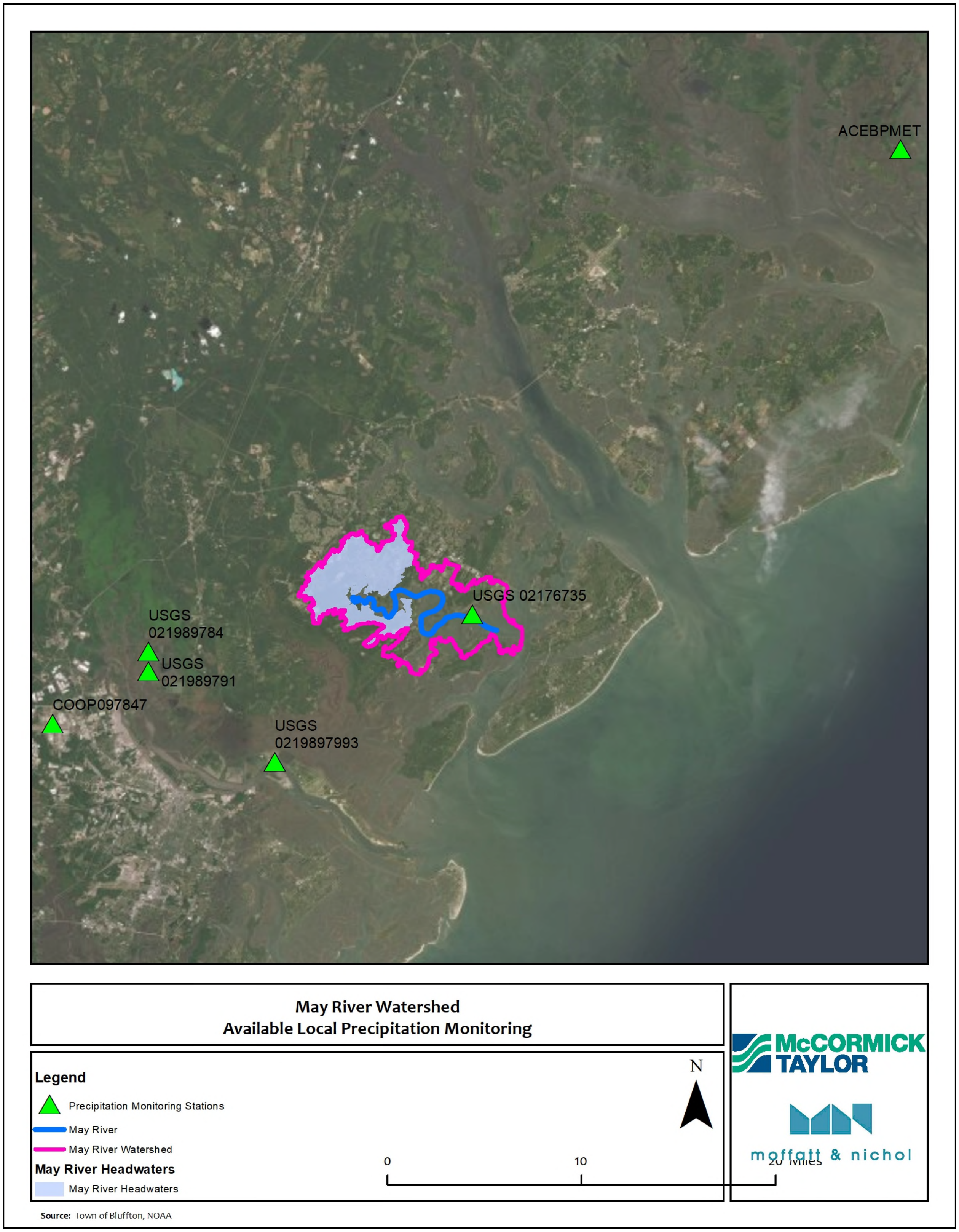

Figure 14. Locations of Precipitation Monitoring Stations

Table 17: Monthly Precipitation Data (inches) at KSAV Savannah Municipal Airport

Month	2002	2018
January	2.38	1.07
February	1.55	1.76
March	5.29	1.22
April	0.4	4.33
May	0.99	6.71
June	8.62	2.57
July	3.29	5.54
August	4.4	3.08
September	5.28	2.1
October	4.36	2.79
November	4.61	3.64
December	3.87	8.14
Total	45.04	42.95

Analysis was conducted to determine the validity of using Savannah airport station data to represent precipitation in the May River project area, as the Savannah station is approximately twenty miles from the study area. Hourly precipitation at KSAV Savannah Municipal Airport was aggregated to create daily precipitation values for comparison to the daily values recorded at the USGS 02176735 May River station, which is located just downstream from the headwater subwatersheds. Figure 15 shows a plot of the two datasets of daily values from June 2002 through June 2004 for comparison. The two records show similar overall precipitation patterns and magnitudes, supporting the assumption that Savannah airport data is a reasonable surrogate for use in the May River model.

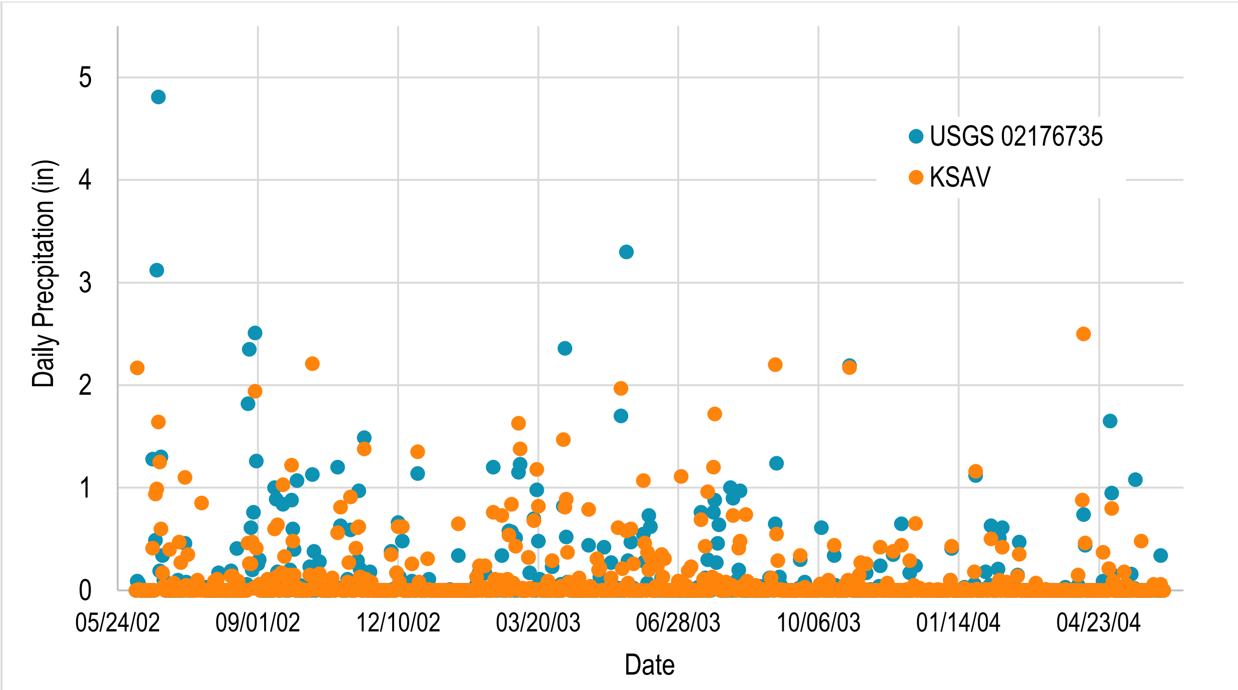

Figure 15. Locations Comparison between USGS 02176735 daily precipitation and KSAV hourly precipitation aggregated to daily values from 2002-2004

2.5.2 Evaporation/Evapotranspiration

James et al. (2005) indicate that event simulations are mostly insensitive to evaporation assumptions, but evaporation is significant during continuous long-term simulations. Daily potential evapotranspiration (PET) values (inches per day) were calculated using the Hamon method, which utilizes daily average temperature, latitude, Julian day of the year, and a monthly variable coefficient. Lu et al. (2005) include Hamon as one of the preferred methods for the Southeast, among others. The monthly variable coefficients, which allow for additional seasonal adjustment of evaporation values within the model, were set to default values from US EPA (2019).

Calculated PET values were compared to values provided in Amatya et al. (2018) for coastal South Carolina. The calculated Hamon PET values ranged from 0.02 to 0.24 in/day for both 2000-2004 and 2015-2018. The range shown in Amatya et al. (2018) was approximately 0.04 to 0.22 in/day for South Carolina (taken from monthly means and adjusted to daily), indicating that the calculated Hamon PET values are reasonable for use in the May River study area. Calculated PET values were used to generate monthly-averaged daily PET values over the range of the baseline (2001-2005) and current (2014-2019) conditions, as illustrated in Figure 16. Calculated PET values shown in the Table 18 were used as initial evaporation values within XPSWMM. These values were modified during the model adjustment process in order to attain proper hydrologic water balance, further discussed in the Model Calibration section.

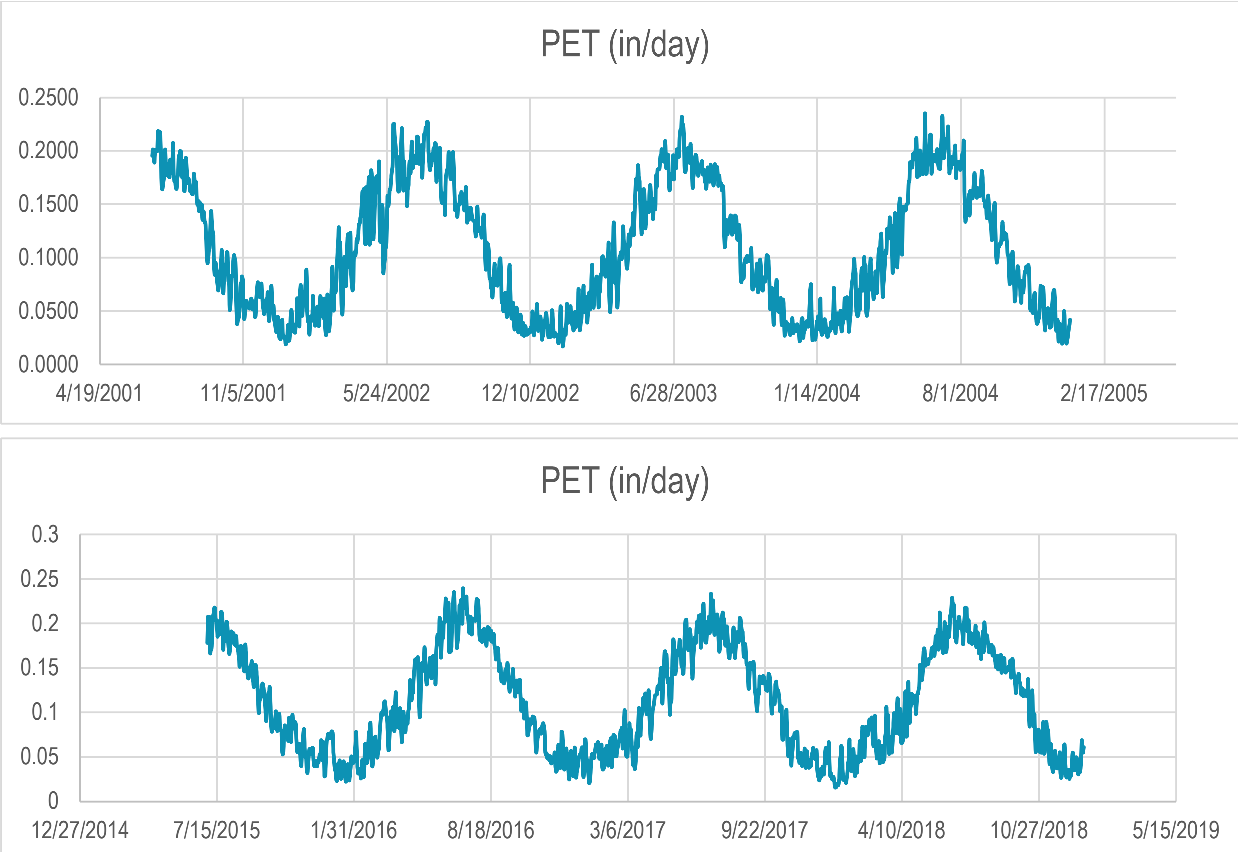

Figure 16. Daily Average PET values for baseline and current conditions

Table 18: Daily PET Values by Month

	2000-2004	2015-2018
Month	Daily PET (in/day)	Daily PET (in/day)
January	0.05	0.04
February	0.06	0.06
March	0.09	0.08
April	0.11	0.11
May	0.16	0.15
June	0.19	0.19
July	0.20	0.20
August	0.18	0.17
September	0.14	0.14
October	0.09	0.09
November	0.06	0.06
December	0.04	0.05

2.6 Subcatchment Parameters

Subcatchment parameters for hydrology were developed using the DEM, land use data, and aerial imagery. Parameters include subcatchment **area**, **width**, **slope**, and **impervious percentage**. The impervious percentage for each subcatchment was calculated for both 2002 and 2018 using impervious data discussed in Section 2.3 Impervious Cover. Subcatchment area, width, and slope were kept the same for 2002 and 2018, as the subcatchment shapes themselves do not change between the baseline and current conditions.

Additional subcatchment parameters were developed to support the infiltration portion of the rainfall-runoff simulation. The impervious and land use datasets were used to calculate area-weighted overland **Manning's n roughness coefficients** for the pervious portions of each subcatchment. To generate the pervious area datasets for 2002 and 2018, the 2002 impervious areas were subtracted (using the "Erase" analysis tool in the advanced license extension for ArcGIS) from the 2001 NLCD land use dataset, and the 2018 impervious areas were subtracted from the 2016 NLCD land use dataset. A Manning's n roughness value was assigned to each pervious land use category present in the study area, using the SWMM Hydrology Manual, Chow, TR-55, and SWMM User Manual as reference literature (as listed in Table 19). All impervious surfaces were assumed to have a Manning's n value of 0.013, which is the roughness value for concrete and asphalt (Chow, 1959).

Table 19: Manning's Roughness Coefficient Values for Pervious Areas

Land Use (NLCD)	**Manning's n**	**Source**
Developed Open Space	0.075	SWMM hydro manual – Parks/lawn
Developed Low Intensity (pervious portion)	0.05	TR-55
Developed Medium Intensity (pervious portion)	0.05	TR-55
Developed High Intensity (pervious portion)	0.038	TR-55
Barren Land	0.03	SWMM hydro manual – Moderate bare soil
Deciduous Forest	0.4	Hybrid of TR-55 and SWMM 5.1 user manual – forest
Mixed Forest	0.4	Hybrid of TR-55 and SWMM 5.1 user manual – forest
Evergreen Forest	0.4	Hybrid of TR-55 and SWMM 5.1 user manual – forest
Shrubland	0.12	SWMM hydro manual – shrubs and bushes
Grassland	0.1	SWMM hydro manual – dense grass
Pasture	0.055	SWMM hydro manual – pasture
Cultivated Cropland	0.035	Chow – cultivated areas, mature row crops
Woody Wetlands	0.075	Chow – floodplain, with growth of trees and sprouts
Herbaceous Wetlands	0.05	Chow – floodplain, medium brush

Values for **depression storage** were developed by calculating an area-weighted average of recommended depression storage values for various pervious land use types. Depression storage was calculated as 0.15 inches for Managed/Developed pervious land uses and 0.3 inches for Forested/Vegetated pervious land uses (Rossman, 2010). The depression storage value was set at 0.07 inches for all impervious surfaces. Values for the percentage of subcatchment area that contains zero depression storage were kept at the XPSWMM default value of 25 percent for all subcatchments.

2.7 Infiltration and Groundwater

The continuous model required representation of baseflow in the stream channels. Properties influencing the rate and volume of infiltration, evaporation, storage, movement, and discharge of water from shallow groundwater into streams are contained in the Infiltration and Groundwater sections of XPSWMM. Since this is a continuous simulation, both were used (as opposed to an event model that might only be concerned with infiltration). XPSWMM provides four methods to select for modeling infiltration in pervious areas: Horton, Green Ampt, Uniform Loss, and SCS Curve Number. For the May River Headwaters model, the Horton approach was selected because it works well for long-term hydrology simulations and is sensitive to differences in hydrologic soil group (HSG). The Horton approach is empirical and models infiltration capacity as a function of time as $Fp = Fc + (F_0\text{-}Fc)e^{-kt}$, where

Fp = infiltration rate into soil (in/hr),

Fc = minimum or asymptotic value of Fp (in/hr),

F_0 = maximum initial value of Fp (in/hr),

t = time from beginning of storm (sec), and

k = decay coefficient (1/sec).

When both infiltration and groundwater are modeled in XPSWMM, stormwater that infiltrates into the soil accumulates in and percolates through an unsaturated upper soil zone. Evapotranspiration (ET) produces water losses from the upper zone. Percolating water enters the saturated lower soil zone, which leads to a rise in water table (saturated zone) elevation. At the same time, groundwater is discharged from the saturated lower soil zone to the stream if the water table elevation is higher than the stream channel water elevation. The rate of groundwater discharge is dependent in part on the difference in elevation between the water table and the stream water surface elevation. Water can also be lost from the saturated lower zone through ET, as well as deep percolation to a regional aquifer system.

2.7.1 Infiltration Parameters

Infiltration parameters were developed using soils data from USDA's Web Soil Survey and land use data. Minimum infiltration rates were developed by calculating an area-weighted average of literature-recommended infiltration values based on the proportion of each hydrologic soil group (A, B, C, D) present within each subcatchment (Table 20) (James et al, 2005). Maximum infiltration values were computed based on the proportion of heavily vegetated pervious versus managed pervious area within each subcatchment, using recommended infiltration rates for these two types of pervious area (Table 21) (James et al., 2005). The XPSWMM default value of 0.001/sec for decay rate of infiltration was used for all subcatchments. No maximum infiltration was assigned.

Table 20: Minimum Infiltration Rates

HSG	in/hr
A	0.37
B	0.22
C	0.1
D	0.03

Table 21: Maximum Infiltration Rates

Pervious Area	in/hr
Managed/Developed Pervious	5
Forest/Heavy Vegetation	10

2.7.2 Groundwater Parameters

Groundwater setup in XPSWMM is divided into four categories: aquifer/water table depths and thicknesses, evapotranspiration, infiltration/percolation, and groundwater outflow. Several parameters within each category were developed in order to model groundwater flow. A total of 13 parameters were developed, including water table elevation, porosity, wilting point, field capacity, hydraulic conductivity, and more. This collection of parameters, in combination with the surface infiltration and runoff setups, drives the interaction between precipitation, surface runoff, infiltration, evaporation/evapotranspiration, and groundwater flow.

Parameters were calculated using a combination of USDA Web Soil Survey soils data, USGS geologic & groundwater data, input from water resources professionals from SC Department of Natural Resources (SCDNR) and Center for Watershed Protection, previous long-term continuous XPSWMM modeling experience, and professional engineering judgement. Initial groundwater parameters are provided in Table 22.

Table 22: Initial Groundwater Parameters

Parameter	Initial Value	Development Information
Upper Zone Depth (Depth to Water Table)	1.41 ft	Water table depth data provided in USDA Web Soil Survey data; USGS groundwater data used as additional reference
Lower Zone Depth (Aquifer Depth)	20 ft	Initial guess based on previous modeling experience and engineering judgement
Wilting Point	0.09	Calculated using USDA Web Soil Survey data
Field Capacity	0.17	Calculated using USDA Web Soil Survey data
Fraction of ET Assigned to Upper Zone	0.95	Initial guess based on previous modeling experience and engineering judgement
Max Depth of Significant Lower Zone ET	7 ft	Initial guess based on previous modeling experience and engineering judgement
Saturated Hydraulic Conductivity	7.4 in/hr	Calculated using USDA Web Soil Survey data
Porosity	0.45	Calculated using USDA Web Soil Survey data
Curve Fitting Parameter	45	Initial guess based on USDA Web Soil Survey data and SWMM guidance
Initial Upper Zone Moisture	0.17	Set equal to Field Capacity based on previous modeling experience and engineering judgement
Coefficient for Unquantified Losses	0.0009 in/hr	Initial guess based on previous modeling experience and engineering judgement
Tension/Soil Moisture Slope	1.25	Initial guess based on previous modeling experience and engineering judgement
Groundwater Flow Coefficient	0.00016	Initial guess based on previous modeling experience and engineering judgement

Following initial parameter development, several values were modified in order to achieve a proper surface-subsurface water balance, further discussed in the Model Calibration section.

2.8 Water Quality Parameters (Fecal Coliform)

Land surface pollutant loading in XPSWMM is represented using a build-up and wash-off approach. Pollutant build-up occurs in both natural and developed environments from multiple sources. For example, detached soil and waste from wild and domestic animals accumulates on land surfaces over time. During precipitation events, runoff carries these pollutants off surfaces and into streams. In XPSWMM, parameters defining build-up and wash-off processes are uniquely defined for each land use and a few different methods are available for both build-up and wash-off, such as exponential function and Event Mean Concentration (EMC) approaches. An EMC method is used for the May River Headwaters model. In this case, a fixed concentration is associated with runoff (Table 23) with no limit on available buildup. In developed areas where septic systems were present, the EMC values were increased initially by 20 percent based on professional modeling judgement since local information on septic performance and contributions to fecal loading was limited. Initial values are assigned as follows using information from the TMDL created for Fecal Coliform for the Shellfish Harvesting Areas in the Lockwoods Folly River, Lumber River Basin in North Carolina (NCDENR, 2010). These are within the range of values used for the May River Water Quality Model (2002), which were 140 to 6600 #/100 mL for runoff. Final values were determined through a calibration process, further discussed in the Model Calibration section.

Table 23: Initial Fecal Coliform EMC Values for Land Cover

Land Cover	Land Use Code	Initial FC Value (#/100 ml)
Open Water	11	400
Developed, Open Space	21	2500
Developed, Low Intensity - Sewer	22	5150
Developed, Low Intensity - Septic	22	6180
Developed, Medium Intensity - Sewer	23	5150
Developed, Medium Intensity - Septic	23	6180
Developed, High Intensity - Sewer	24	4000
Barren Land	31	400
Deciduous Forest	41	400
Evergreen Forest	42	400
Mixed Forest	43	400
Shrubland	52	400
Grassland	71	400
Pasture	81	400
Cultivated Crops	82	400
Woody Wetlands	90	400
Emergent Herbaceous Wetlands	95	400

The maximum number of land use categories that can be assigned to a single subcatchment in XPSWMM is five. Therefore, the Project Team aggregated the 17 land cover categories (from Table 23) as shown below (Table 24). These EMC differentiate between developed and undeveloped (natural) land covers. Additionally, the land use categories for low and medium density development are separated into two categories to distinguish between areas that are connected to sanitary sewer or septic systems.

Table 24: Fecal Coliform EMCs for XPSWMM Land Use

XPSWMM Land Use Category	Land Covers Included	Land Use Codes Included	Initial FC Value (#/100 ml)
Developed, Open Space	Developed, Open Space	21	2500
Developed, Low/Medium Intensity - Sewer	Developed, Low Intensity – Sewer; Developed, Medium Intensity – Sewer	22, 23	5150
Developed, Low/Medium Intensity - Septic	Developed, Low Intensity – Septic; Developed, Medium Intensity - Septic	22, 23	6180
Developed, High Intensity - Sewer	Developed, High Intensity - Sewer	24	4000
Natural/Open Water	Barren Land; Deciduous Forest; Evergreen Forest; Mixed Forest; Shrubland; Grassland; Pasture; Cultivated Crops; Woody Wetlands; Emergent Herbaceous Wetlands	31, 41, 42, 43, 52, 71, 81, 82, 90, 95	400

Once runoff is transported to the stream channel, in-stream pollutant processes are limited in XPSWMM to a simple exponential decay, which is used to represent bacteria die-off within the stream network. An initial decay value of 1.0 (units of 1/day) was used based on professional modeling judgement. Die off rates of 0.8 per day were used in May River Water Quality Model (Lopez and Wagner, 2002), prepared by Thomas & Hutton Engineering and Camp Dresser & McKee. Initial FC concentrations were assumed to be zero in groundwater because there are no significant point sources for consideration in the project area. However, fecal EMCs, the decay coefficient, and groundwater concentrations were adjusted during model calibration, further discussed in the Model Calibration (Section 3.0).

2.9 Existing BMPs

The predominant structural stormwater BMP utilized by the Town of Bluffton is stormwater ponds. As summarized in Table 25, the number of ponds has increased dramatically between the baseline and current conditions, most notably in Rose Dhu Creek and Stoney Creek subwatersheds. The Project Team in consultation with the Town, decided that the net effect of all structural BMPs in the May River Headwaters watersheds is implicit in the model results (as a function of land use and water quality calibration) at the outlets. There were documented challenges (see §5.4.2) that made incorporation of discrete, individual BMPs in the XPSWMM model unattainable. However, the Team is confident the model is a useful tool that will allow the Town to estimate the effect of current and future BMPs.

Table 25: Wet Ponds in May River Headwaters

Year	Duck Pond	Palmetto Bluff	Rose Dhu Creek	Stoney Creek	Total
2002	5	1	1	15	22
2018	7	20	142	93	262
Increase	40%	1,900%	14,100%	5,200%	1,091%

2.9.1 Proposed Projects in the 2011 May River Action Plan (Action Plan)

After reviewing the current Action Plan with the Town, the Project Team was informed that two of the fourteen (14) proposed projects (Table 26) were constructed in the May River Headwaters: the New Riverside Pond (NRP) and the Pine Ridge stormwater pond irrigation system (Areas A and H in Figure 17). The NRP project was created to enhance removal efficiency for bacteria at a known FC hotspot in the Stoney Creek watershed. The Pine Ridge irrigation system, located in the Rose Dhu Creek watershed, was designed to achieve stormwater volume reduction through application and infiltration on turfgrass areas.

Four of the 2011 proposed Action Plan projects (J, K, L and M, Figure 17) fall outside of the boundaries of the WQ Model project scope work area. However, Project Area K, primarily composed of the National Register Historic District of Bluffton, the Theodore D. Washington Municipal Building (Bluffton Town Hall) parking lot retrofits to reduce impervious surface and provide water quality improvements were completed. Funding for the NRP, Pine Ridge, and Town Hall cooperative projects was provided in part by the South Carolina Department of Health and Environmental Control with funds from the U.S. Environmental Protection Agency under Section 319 of the Clean Water Act. In addition, Project Area K currently includes CIP projects which will provide water quality BMPs to retain/infiltrate stormwater runoff as a retrofit of existing impervious surfaces pre-dating required stormwater BMPs.

Utilizing the procedure for the Watershed Treatment Model (WTM) in §5.4.2 of this model report, the estimated annual benefits for NRP and Pine Ridge projects are summarized in Table 27. Note that under the new *Southern Lowcountry Stormwater Design Manual*, ponds do not receive runoff reduction credit. Also, the Pine Ridge irrigation system was modeled as an infiltration practice based on average daily irrigation applications as listed in the report produced by the consultant (Thomas & Hutton, 2015).

Table 26: Recommended BMPs in 2011 May River Watershed Action Plan

Area	Project	Description
A	Future New Riverside Area	Construct three new stormwater ponds, modify one existing stormwater pond
B	Kenzie Park Outfall	Construct new stormwater pond
C	Rose Dhu Creek	Construct one new stormwater pond
D	Buckwalter Community Park and The Farm	Construct ditch modifications in existing ditch to divert water into adjacent ponds/wetland restoration
E	Ditch north of Stoney Crest	Construct earthen ditch blocks in existing ditch/wetland restoration
F	Hampton Lake Retrofit	Pond modification
G	Lakepoint Drive	Pond modification for up to nine existing stormwater ponds
H	Pinecrest	Modify five stormwater ponds
I	Pinecrest	Modify three stormwater ponds
J	Town Property	Expand existing Town stormwater pond
K	Guerrard/Wharf St.	Construct four new stormwater ponds
L	Gascoigne Bluff	Construct four new stormwater ponds
M	Traver Tract	Modify three existing stormwater ponds
N	Ditch in Hampton Lake	Construct earthen ditch blocks in existing ditch/wetland restoration

Table 27: Benefits of Completed 2011 Action Plan Projects

Project	Water Quality Volume (ft^3)	TN (lbs/yr)	TP (lbs/yr)	TSS (lbs/yr)	Bacteria (billion/yr)	Runoff Reduction (ac-ft/yr)
New Riverside Pond	152,896	152.25	127.03	6834.63	9535.4	0
Pinecrest Irrigation	5,909	81.5	18.02	4.34	324.15	2.44
TOTAL	158,805	233.75	145.05	6,838.97	9,859.55	2.44

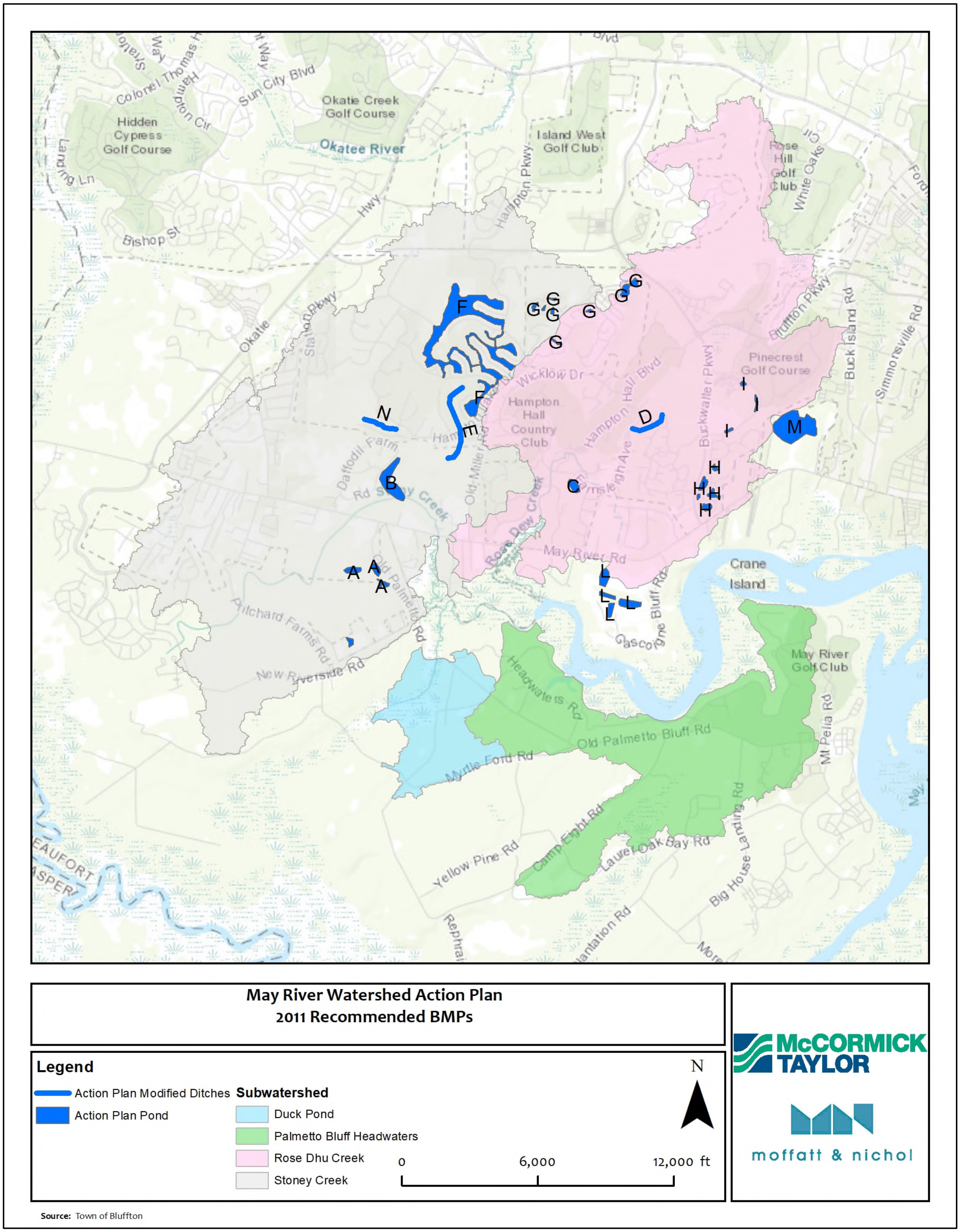

Figure 17. 2011 May River Watershed Action Plan Recommended BMPs

3.0 Model Calibration

To capture a variety of storm events, baseflow conditions, long-term trends, and variability in pollutant generation, transport, and fate, a continuous simulation of both water quantity and quality within the XPSWMM environment was developed. The Project Team developed and analyzed two conditions:

1. Baseline Conditions, 2002
2. Current Conditions, 2018

Therefore, in addition to using land use, land cover, imperviousness, and meteorology associated with each time period, the model calibration approach was designed to simulate and achieve model fit for periods of time including and surrounding these years. The simulation time periods stretched beyond just the two conditions to allow time at the beginning of the baseline and current periods for the model to ramp-up, helping to properly define antecedent soil moisture and baseflow conditions. For the baseline period, a model spin-up was used (running from January to December 2000) and the simulation extended through December 2004. For current conditions, spin-up was from July to December 2015. The current conditions model simulation extended through December 2018.

The initial approach called for calibration of both flow and water quality using existing data sources. After further review of the flow data, it was determined that the locally available data was not sufficient to calibrate the model to flow. Therefore, a number of other comparisons were made to ensure the model was producing a reasonable rainfall-runoff response, as described in sections 3.1.3, 3.1.4, and 3.1.5. This approach falls short of a formal, more complete calibration given these limitations on data, which are described further below. However, the combination of the methods used to evaluate hydrologic response of the model with the water quality calibration suggests the current model is appropriate for use in comparing baseline and current conditions as well as evaluation of management scenarios on a relative basis rather than an absolute basis.

3.1 Hydrology Model

XPSWMM has the ability to model water quality parameters, like FC, but only in the sanitary setting. The drawback of this setting is that there is reduced accuracy with the hydrologic and hydraulic modeling. In this section, we will describe the process for calibrating the hydrology model. Local flow data from the Town and USGS were reviewed for use in the hydrology model calibration. These efforts are described below. Ultimately, these data sources could not be used as planned, and therefore the model was evaluated by considering the overall model water balance in comparison to regional literature values. In addition, the Project Team compared model output to nearby gages (outside of the watershed; drainage area adjusted) to demonstrate overall runoff trends and flow magnitudes. The goal of the latter comparison was not to match the adjusted gage data but rather to ensure our rainfall-runoff response was generally consistent with patterns observed in the region.

3.1.1 Town of Bluffton Flow Data

The overall hydrologic calibration goal was to calibrate the XPSWMM models to flow data provided by the Town for the baseline 2002 time period and validate the models to flow data recorded during the current 2018 time period supplemented by USGS data. Velocity data collected by the Town using a SonTek-IQ is present in short intervals (several minutes) for multiple stations across the Stoney Creek and Rose Dhu Creek subwatersheds for 2016 through 2018, but the Project Team was advised by the Town not to utilize this data for velocity/flow comparisons (Table 24) due to concerns with data accuracy. Flow data collected using a SonTek FlowTracker 2 for station SC4 in the Stoney Creek subwatershed is available for portions of 2016 and 2017, but there are significant data gaps and the flow magnitudes within the dataset are unexpectedly small for a subwatershed of Stoney Creek's size. Overall, the flow data provided did not offer consistent, continuous coverage for any of the four project subwatersheds for either the baseline or current time periods.

3.1.2 Local USGS Gages

Three USGS gages along the main stem of the May River have recorded flow data for portions of the baseline 2002 time period, with USGS 02176711 located closest to the project area (Table 28). Several numerical methods were applied in an attempt to eliminate tidal effects in the recorded flow gage data at USGS 02176711. These methods were successful at removing low-frequency astronomical tidal effects from the flow data but were unable to separate high-frequency river flow from high-frequency offshore meteorological activity (i.e., local winds, etc.). The Palmetto filter, a tidal adjustment tool used by researchers at SCDNR, was also explored as a method of removing tidal signals from the USGS flow gage data. The Palmetto filter produced a flow time series with reduced tidal variability, but it is difficult to discern whether all tidal influence has been removed by the filter, as negative flow values still occur throughout the time series (indicating flow in the upstream direction). Since the overall watershed signal is small in comparison to the tidal signal, it is difficult to separate the two without considerable effort which was beyond the resources available for the project. Therefore, model development proceeded without further use of this flow data. Realizing that this is a limitation of the current model, the Team has made recommendations for future refinements of the model (Table 34) based on enhanced flow monitoring recommendations (Section 5.1.3).

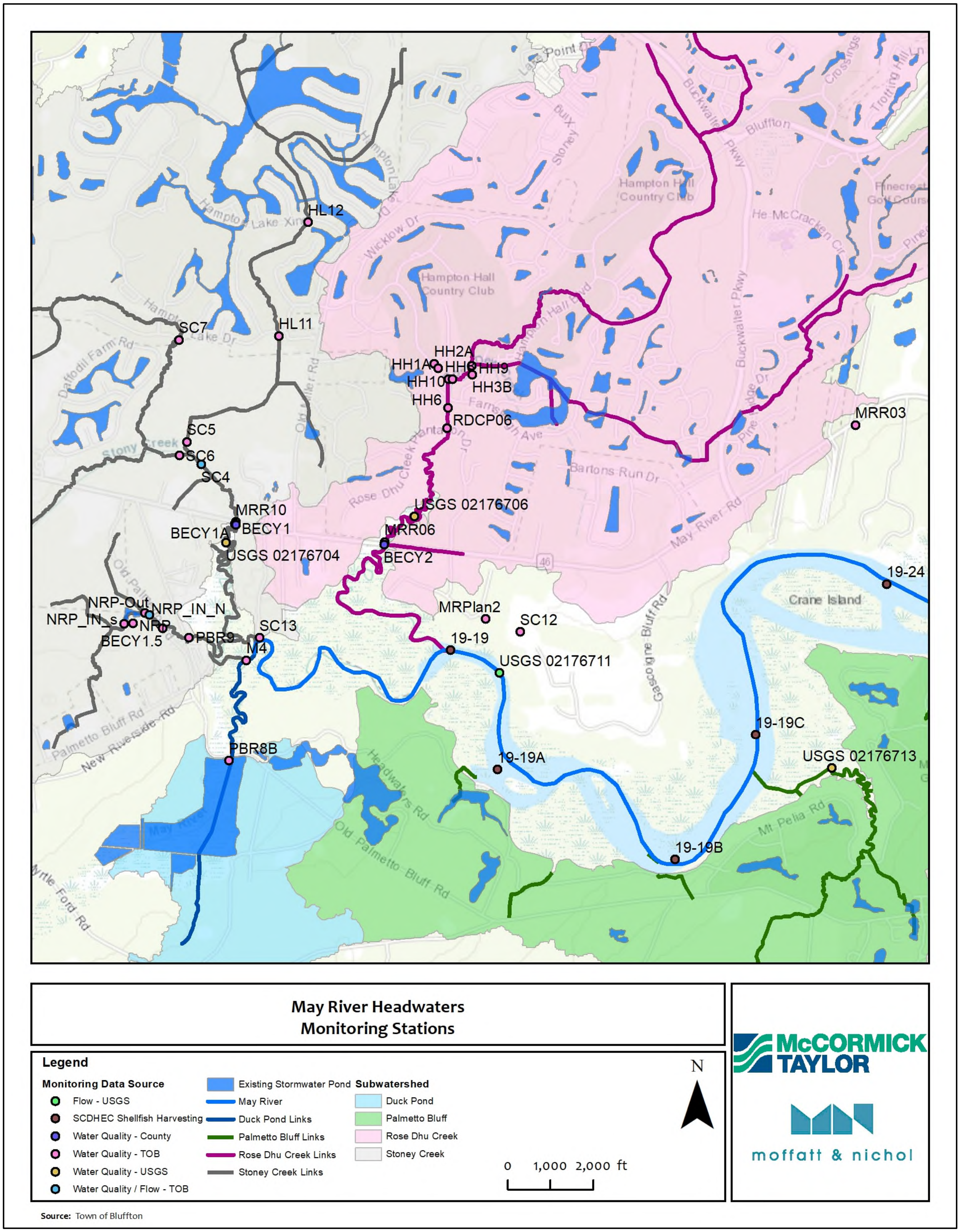

Figure 18. Water Quality and Flow Monitoring Stations

Table 28: Available Flow Data in May River Watershed

Data	Time Period	Location	Station	Collection Agency
Velocity, Temperature	10/4/2017 - 1 minute	Main Stem	BV01	TOB
Velocity, Temperature	10/4/2017 - 2 minutes	Main Stem	BV01	TOB
Velocity, Temperature	1/17/2018 - 6 minutes	Main Stem	BV01	TOB
Velocity, Temperature	5/15/2019 - 5 minutes	Main Stem	HGC01	TOB
Velocity, Temperature	10/4/2017 - 2 minutes	Main Stem	HGC01	TOB
Velocity, Temperature	1/17/2018 - 4 minutes	Main Stem	HGC01	TOB
Velocity, Temperature	5/10/2018 - 2 minutes	Main Stem	HGC01	TOB
Velocity, Temperature	6/11/2019 - 3 minutes	Main Stem	HGC01	TOB
Velocity, Temperature	2/7/2019 - 2 minutes	Main Stem	HGC01	TOB
Velocity, Temperature	5/10/2018 - 3 minutes	Rose Dhu Creek	HH6	TOB
Velocity, Temperature	2/7/2019 - 8 minutes	Rose Dhu Creek	HH6	TOB
Velocity, Temperature	5/15/2019 - 7 minutes	Rose Dhu Creek	HH6	TOB
Velocity, Temperature	6/11/2019 - 7 minutes	Rose Dhu Creek	HH6	TOB
Velocity, Temperature	8/2/2017 - 4 minutes	Unknown	MMR2	TOB
Velocity, Temperature	6/11/2019 - 1 minute	Unknown	MMR2	TOB
Velocity, Temperature	8/2/2017 - 2 minutes	Main Stem	MRR01	TOB
Velocity, Temperature	1/17/2018 - 1 minute	Main Stem	MRR01	TOB
Velocity, Temperature	2/7/2019 - <1 minute	Main Stem	MRR01	TOB
Velocity, Temperature	10/4/2017 - 3 minutes	Main Stem	MRR02	TOB
Velocity, Temperature	10/10/2017 - 2 minutes	Main Stem	MRR02	TOB
Velocity, Temperature	1/17/2018 - 2 minutes	Main Stem	MRR02	TOB
Velocity, Temperature	2/7/2019 - 1 minute	Main Stem	MRR02	TOB
Velocity, Temperature	6/11/2019 - 2 minutes	Stoney Creek	PBR9	TOB
Velocity, Temperature	5/15/2019 - 3 minutes	Unknown	PBRW	TOB
Velocity, Temperature	5/15/2019 - 18 minutes	Stoney Creek	SC4	TOB

Data	Time Period	Location	Station	Collection Agency
Velocity, Temperature	6/11/2019 - 12 minutes	Stoney Creek	SC4	TOB
Flow, Velocity, Temperature, Stage	7/28/2016 - 11/30/2016 (15 minute interval, some gaps)	Stoney Creek	SC4	TOB
Flow, Velocity, Temperature, Stage	7/28/2016 - 2/1/2017 (15 minute interval, some gaps)	Stoney Creek	SC4	TOB
Flow, Velocity, Temperature, Stage	7/28/2016 - 4/27/2017 (15 minute interval, some gaps)	Stoney Creek	NRP-OUT	TOB
Flow	6/1/2002 - 9/29/2004 (gaps 10/2002 - 10/2003, 11/2003, 12/2003)	Main Stem	USGS 02176711	USGS
Flow	6/6/2002 - 6/9/2004 (gaps 6/2002 - 7/2002, 12/2003)	Main Stem	USGS 02176720	USGS
Flow	6/6/2002 - 6/8/2004 (gaps 7/2003, 10/2003)	Main Stem	USGS 02176735	USGS

Note: USGS gage data was collected by the Project Team, not received from the Town.

3.1.3 Hydrologic Parameter Adjustment

During model calibration, multiple model parameters were adjusted from their initial values in order to improve hydrologic model performance. Model performance was evaluated based on overall water balance and by comparing flow patterns to nearby USGS gages, to be discussed in Section 3.1.4 and 3.1.5.

Potential Evaporation/Evapotranspiration (PET):

Calculated monthly-averaged daily PET values (discussed in Section 2.5.2) were modified during calibration in order to optimize performance and to help achieve an appropriate surface water balance. The calculated PET values were decreased by 20% during calibration; initial versus calibrated values are provided in Table 29.

Table 29: Calibrated PET Values for May River Headwaters

	2000-2004		2015-2018	
Month	Initial PET (in/day)	Calibrated PET (in/day)	Initial PET (in/day)	Calibrated PET (in/day)
January	0.05	0.04	0.04	0.03
February	0.06	0.05	0.06	0.05
March	0.09	0.07	0.08	0.06
April	0.11	0.09	0.11	0.09
May	0.16	0.12	0.15	0.12
June	0.19	0.15	0.19	0.15
July	0.20	0.16	0.20	0.16
August	0.18	0.14	0.17	0.14
September	0.14	0.11	0.14	0.11
October	0.09	0.07	0.09	0.07
November	0.06	0.05	0.06	0.04
December	0.04	0.03	0.05	0.04

Groundwater:

Several groundwater parameter values were modified during the calibration process in order to achieve a proper surface-subsurface water balance. Initial and calibrated values are provided in the Table 30.

Table 30: Calibrated Groundwater Values for May River Headwaters

Parameter	Initial Value	Calibrated Value	Calibration Information
Upper Zone Depth (Depth to Water Table)	1.41 ft	5 ft	Modified based on information from SCDNR staff
Lower Zone Depth (Aquifer Depth)	20 ft	30 ft	Modified based on USGS groundwater data
Wilting Point	0.09	0.09	No change
Field Capacity	0.17	0.17	No change
Fraction of ET Assigned to Upper Zone	0.95	0.95	No change
Max Depth of Significant Lower Zone ET	7 ft	7 ft	No change
Saturated Hydraulic Conductivity	7.4 in/hr	7.4 in/hr	No change
Porosity	0.45	0.45	No change
Curve Fitting Parameter	45	45	No change
Initial Upper Zone Moisture	0.17	0.17	No change
Coefficient for Unquantified Losses	0.0009 in/hr	0 in/hr	Modified to eliminate loss to deep groundwater
Tension/Soil Moisture Slope	1.25	1.25	No change
Groundwater Flow Coefficient	0.00016	0.00016	No change

3.1.4 Hydrologic Water Balance

Provided the lack of consistent flow data with which to calibrate the baseline 2002 XPSWMM models, model performance was evaluated in part using an overall hydrologic water balance. Modeled relationships between precipitation, evaporation/ET, infiltration, runoff, and stream baseflow were compared to literature-supported ratios for the region (Cherry et al., 2001; Lu et al., 2005). The literature values provided are for largely forested watersheds, and it should be noted that the May River watershed contained developed areas in the 2002 timeframe although much less than current conditions. Therefore, these literature values were used more as guidance or a benchmark for comparison rather than rule. As previously stated in Table 1, the percent imperviousness in 2001/2002 was 4.19% and 8.21%, respectively for Stoney Creek and Rose Dhu Creek. Water balance benchmarks and modeled values for Rose Dhu Creek and Stoney Creek (2000-2004) are summarized in Table 31. The ratio of runoff to streamflow is closer for Rose Dhu Creek than Stoney Creek, and this may be a reflection of differences in watershed characteristics such as size and shape (Stoney Creek is larger and has a more branched stream system).

Table 31: Water Balance Benchmarks and Modeled Values

Water Balance Benchmark	Modeled Value	
	Rose Dhu Creek	Stoney Creek
ET / Precipitation = 73-76%	75%	76%
Streamflow / Precipitation = 25-30%	28%	24%
Surface Runoff / Streamflow = 76%	75%	85%

3.1.5 Comparison to Nearby USGS Gages

To provide additional insight into the modeled outflow time series, flow data was compiled from two USGS gages outside of the May River watershed. Flow data at the USGS 02176500 gage on the Coosawhatchie River near Hampton, SC and USGS 02175500 gage on the Salkehatchie River near Miley, SC were collected for 2000 through 2004. The watershed area draining to these gages are larger and less developed than the May River watershed, but both gages are in reasonable proximity to the study area to be regionally representative and are located far enough inland to avoid tidal influences. Flow data from the USGS 02176500 and 02175500 gages was scaled via drainage areas separately to the Rose Dhu Creek and Stoney Creek subwatersheds. The goal of the comparison was not to precisely match modeled flow output with the scaled USGS flow, but only that data from these gages could be used to evaluate overall flow patterns and rainfall-runoff behavior. It is expected that flows modeled in XPSWMM will generally be higher than those seen at the USGS gages given that the May River watershed is more developed and will therefore produce higher (and more frequent) runoff volumes. Differences in precipitation patterns between the two USGS gage locations and the May River watershed also affect flow magnitudes, frequencies, and timing.

Figures 19 and 20 show comparisons between XPSWMM's modeled flow results for the Rose Dhu Creek and Stoney Creek subwatersheds and each USGS gage's data scaled down to the appropriate subwatershed drainage area. The comparisons show similar patterns throughout the simulation. As expected, the May River watersheds have higher peaks during wetter periods in 2003 and 2004. Note that periods of 2001 and 2002 were unusually dry for many parts of the region. In summary, the comparison suggests the May River model produces rainfall-runoff behavior consistent with regional expectations.

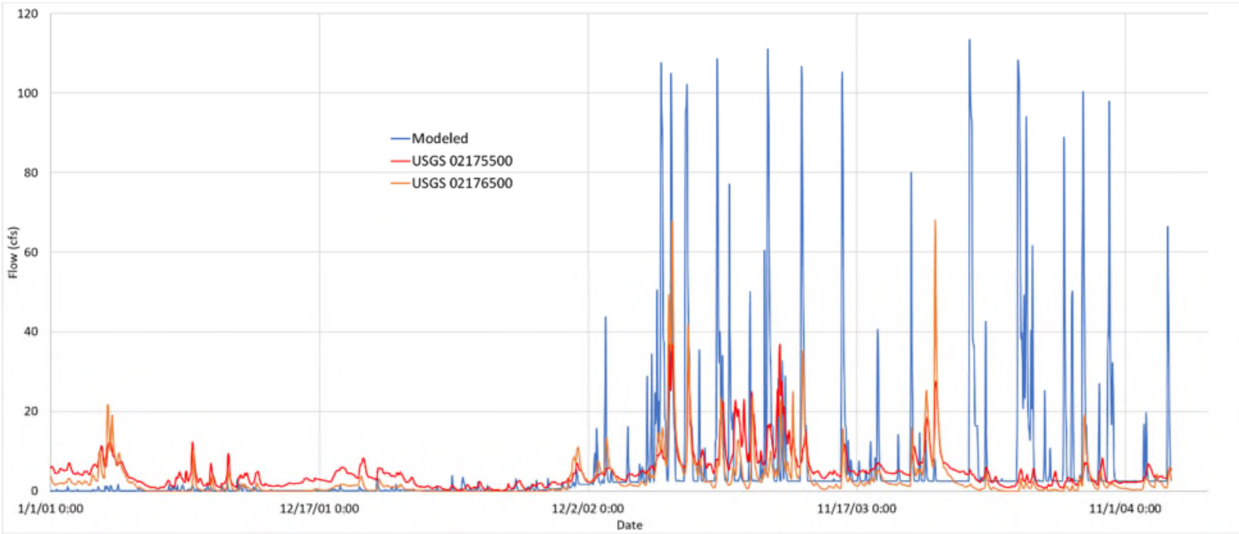

Figure 19. Scaled USGS Gage Data and Modeled Rose Dhu Creek Flow Results

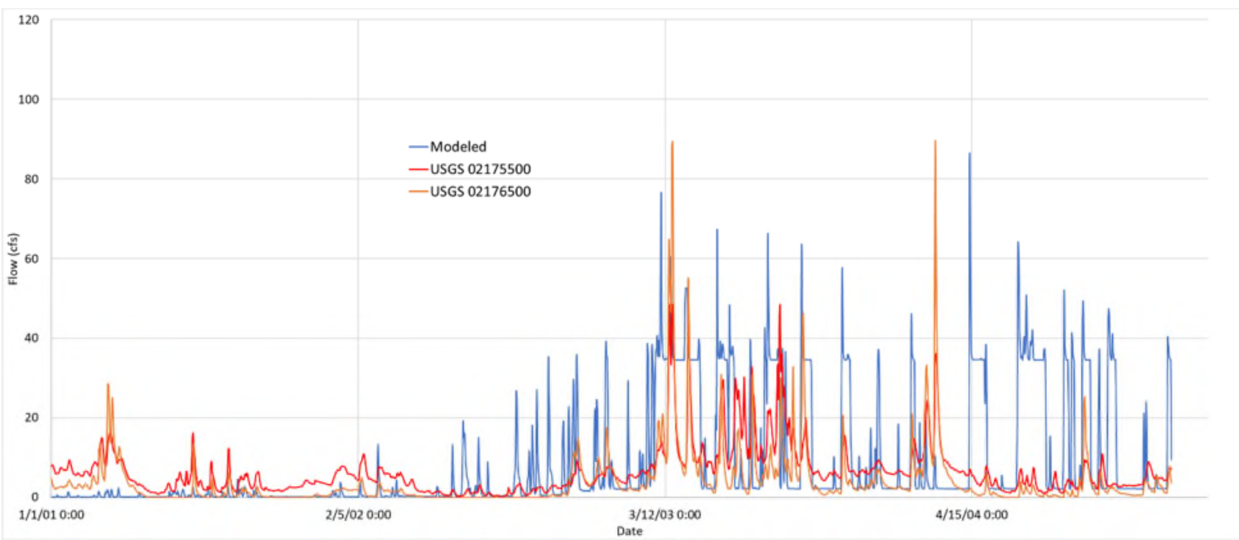

Figure 20. Scaled USGS Gage Data and Modeled Stoney Creek Flow Results

3.2 Water Quality Calibration

3.2.1 Calibration Approach

Watershed loading models are subject to high levels of variability and uncertainty. The model itself is an approximation of reality and the model parameters can only be estimated. There is natural variability in land use and cover, meteorology, and management across the watershed. Next, monitoring data provide an imprecise target for model calibration, as laboratory results have their own associated uncertainty as grab samples may not be fully representative of daily average model predictions. Calibration thus consists of comparing two uncertain numbers, the monitored value and model value. For this reason, the strategy for calibration focused on developing a common set of pollutant-related parameters aimed at fitting the data across years and stations to avoid over-fitting.

Measured FC data were used to calibrate the water quality component of the models. Fecal coliform data was provided by the Town for the current conditions time period. There was limited data available from the baseline period, which included a small amount of FC data from three USGS gages: one located in the Rose Dhu Creek subwatershed, one in the Stoney Creek subwatershed, and another in the Palmetto Bluff subwatershed. Measurements were recorded quarterly from May 2002 until March 2003, providing four measured values for each gage. Review of the Town's bacterial data showed wide variability in concentrations even within short distances along the stream network. Through discussions with the Town, the Project Team confirmed this trend in the monitoring observations (see Section 5.2.2 for more detailed discussion of this statistical analysis). In addition, the Town indicated that although some of the samples collected at the outfalls of some ponds had low FC concentrations, the influx of freshwater into the receiving drainage system (mainly ditches) appears to have supported the regrowth and subsequent spike in fecal coliform concentrations a short distance downstream from the outfall. The Town's staff have demonstrated this phenomenon is not a result of sampling or laboratory process errors, as the effect has been replicated at different times and locations throughout the Headwaters sampling stations. Unfortunately, the model will have trouble simulating this regrowth behavior.

Also, it should be noted that any lack of fit from the hydrology portion of the model will follow through into the water quality simulation. Loads are calculated by multiplying a concentration by a volume of water; therefore, the flow simulation can limit how well the water quality model can reproduce observed magnitudes and patterns. See Table 34 and §5.1 for recommendations for future simultaneous flow and bacteria monitoring.

3.2.2 Water Quality Parameter Adjustment

During model calibration for water quality, multiple parameters were adjusted in order to improve the performance of the water quality simulation in comparison to measured data. Bacterial event mean concentration (EMCs) assigned in the model by land use were adjusted to better fit model output to measured values. Initial versus calibrated fecal concentration values are shown in Table 32. Fecal coliform concentrations were also introduced into groundwater during calibration to reflect the ubiquitous nature of FC in the environment and its interaction with the shallow groundwater table. As the Town continues to enhance its monitoring program (both for flow and FC), the calibration of the model will be able to be further refined.

Table 32: Calibrated EMCs for FC for Land Use

XPSWMM Land Use Category	Initial FC Value (#/100 ml)	Calibrated FC Value (#/100ml)	FC Concentration in Groundwater (#/100ml)
Developed, Open Space	2500	6000	50
Developed, Low/Medium Intensity - Sewer	5150	8000	50
Developed, Low/Medium Intensity - Septic	6180	9500	100
Developed, High Intensity - Sewer	4000	5000	50
Natural/Open Water	400	900	20

Initially during model set up, a simple in-stream decay rate of 1.0 was simulated. However, given that the model could not be calibrated to local flow data and due to the issue of potential bacterial regrowth in channels indicated by Town staff, the Project Team decided to not include decay in the current model. Regrowth is a phenomenon that has been reported elsewhere, and in high organic matter environments can complicate the decay trends (Fries et al., 2007). Once additional flow and bacteria data are collected, this setting can be revisited.

Comparison plots showing observed data and modeled fecal coliform concentrations are provided in Figures 21- 38 for the time periods and nine stations described in Table 33. Note that no station had data available for both the baseline and current conditions. Also, there was no monitoring data available for either time period for Duck Pond. The goals of the calibration were to (1) use the same set of water quality parameters across all subwatersheds and time periods which required a compromise fit across all of them, and (2) achieve a best fit without overfitting the model due to issues with the flow calibration. Two types of graphs are shown for each station. The first is a plot of observed and modeled paired values along a 1-to-1 line (note the modeled value is a daily average) as shown in Figures 21, 23, 25, 27, 29, 31, 33, 35, and 37. The closer the values are to the 1 to 1, the better the fit between observed and modelled. The second plot is a time series of observed and modeled values (Figure 22, 24, 26, 28, 30, 32, 34, 36, and 38). All results plots display results for the time period specified in Table 31 for Baseline and Current Conditions—2001 through 2004 for the Baseline 2002 time period, and 2016 through 2018 for the Current 2018 time period.

Table 33: FC Monitoring Data for Assessing Baseline and Current Conditions

Subwatershed	Baseline 2002 (2001-2004)	Current 2018 (2016-2018)
Rose Dhu Creek	USGS 02176706	MRR06, HH9
Stoney Creek	USGS 02176704	MRR10, PBR9, SC4, SC6
Palmetto Bluff	USGS 02176713	--

Overall, the plots for 2002 (Figures 21-26) show a more limited amount of observed data available for comparison. There is some over prediction and some under prediction. Analysis of the period surrounding 2018 provides a better picture of model performance.

For the 2018 period (Figures 27-38), the paired data comparisons show a generally even distribution of under- and over- prediction with a good amount of scatter around the 1:1 line. However, most plots show underprediction when values are above 1,000 units. Time series show that many of the patterns are captured with a number of high measured values not captured.

The primary goals for the model calibration were to replicate storm event loading and overall loading; replicate the pattern of pollutant concentrations across a range of flows; and reduce the bias (i.e., consistently over or under prediction) in the predictions. The model does a reasonable job of this considering the lack of local flow data to calibration hydrology. However, some of the very high FC concentrations are not captured well in the model in addition to some of the high variability in the data.

In conclusion, the Project Team has developed a set of models based on the available data and resources that can be reasonably applied to understand relative loading between baseline and current conditions and by subcatchment. In addition, it provides a platform to understand the effects of management practices. However, there are several improvements that can be made to refine the model in the future. These recommendations are summarized in Table 34.

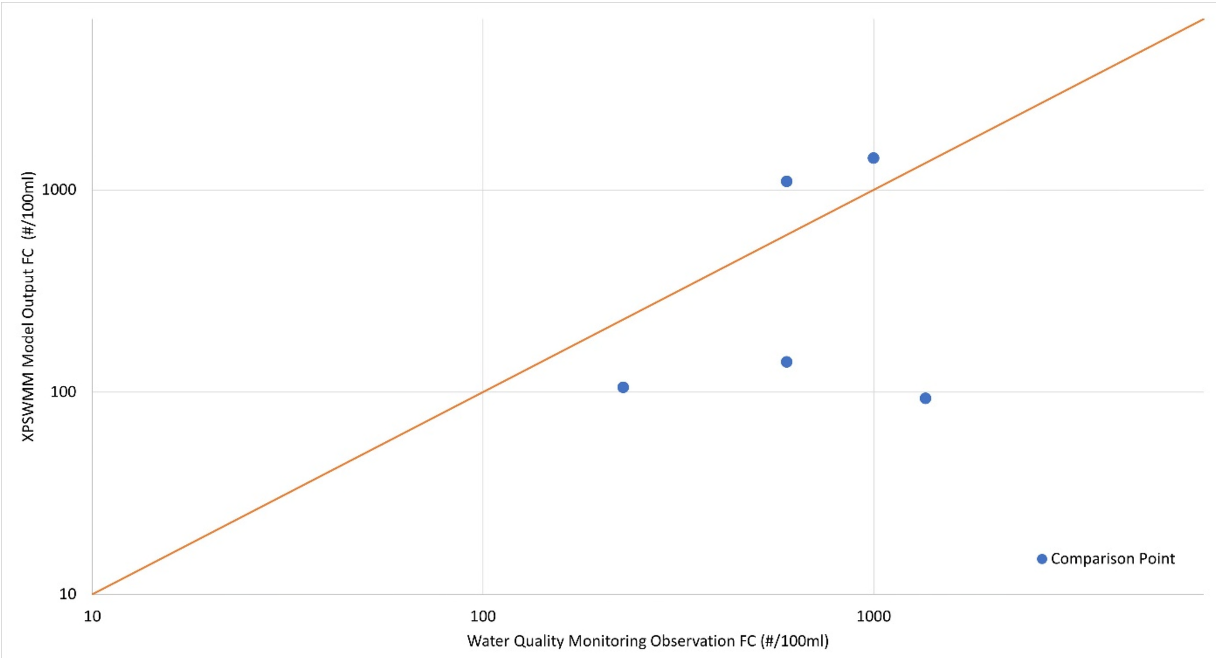

Figure 21. USGS 02176706 Observed vs. Modeled Fecal Concentrations – Baseline Conditions 2002 (Rose Dhu Creek)

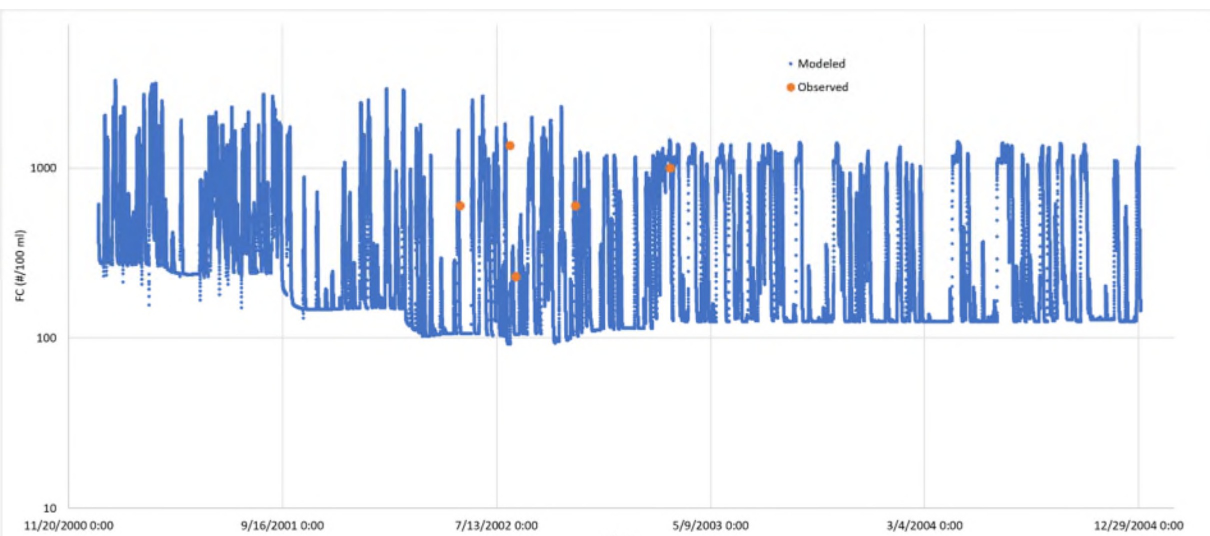

Figure 22. USGS 02176706 Observed and Modeled Fecal Concentrations – Baseline Conditions 2002 (Rose Dhu Creek)

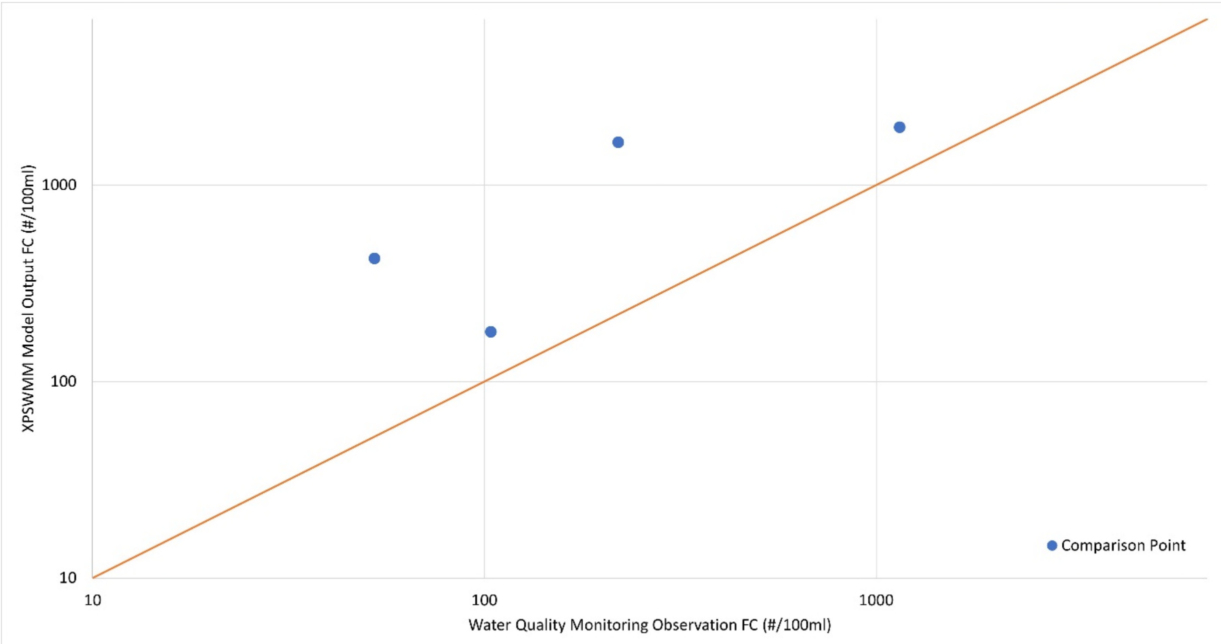

Figure 23. USGS 02176704 Observed vs. Modeled Fecal Concentrations – Baseline Conditions 2002 (Stoney Creek)

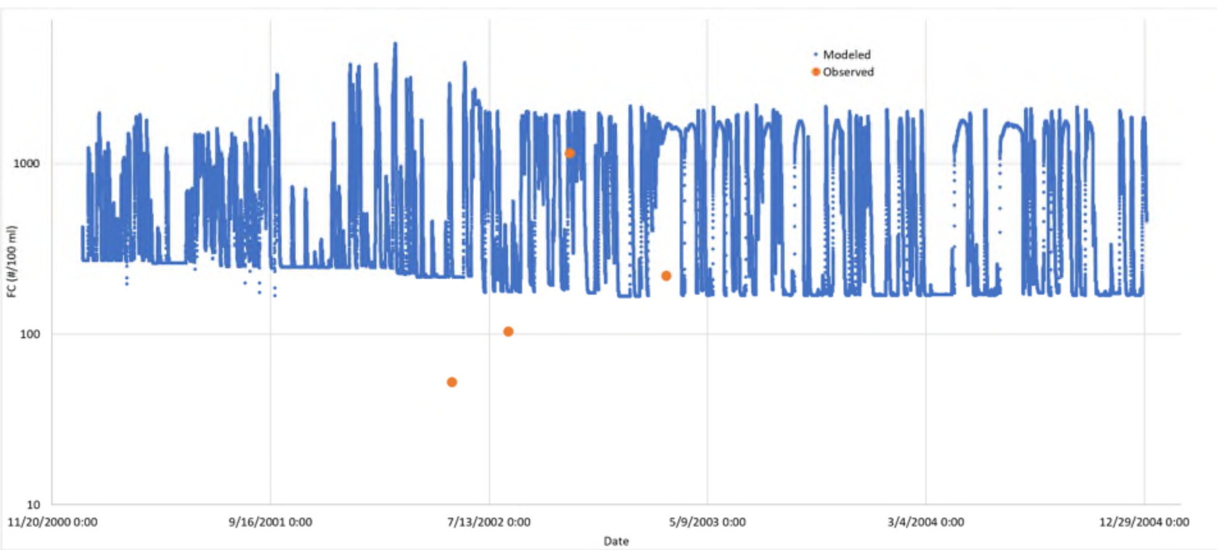

Figure 24. USGS 02176704 Observed and Modeled Fecal Concentrations – Baseline Conditions 2002 (Stoney Creek)

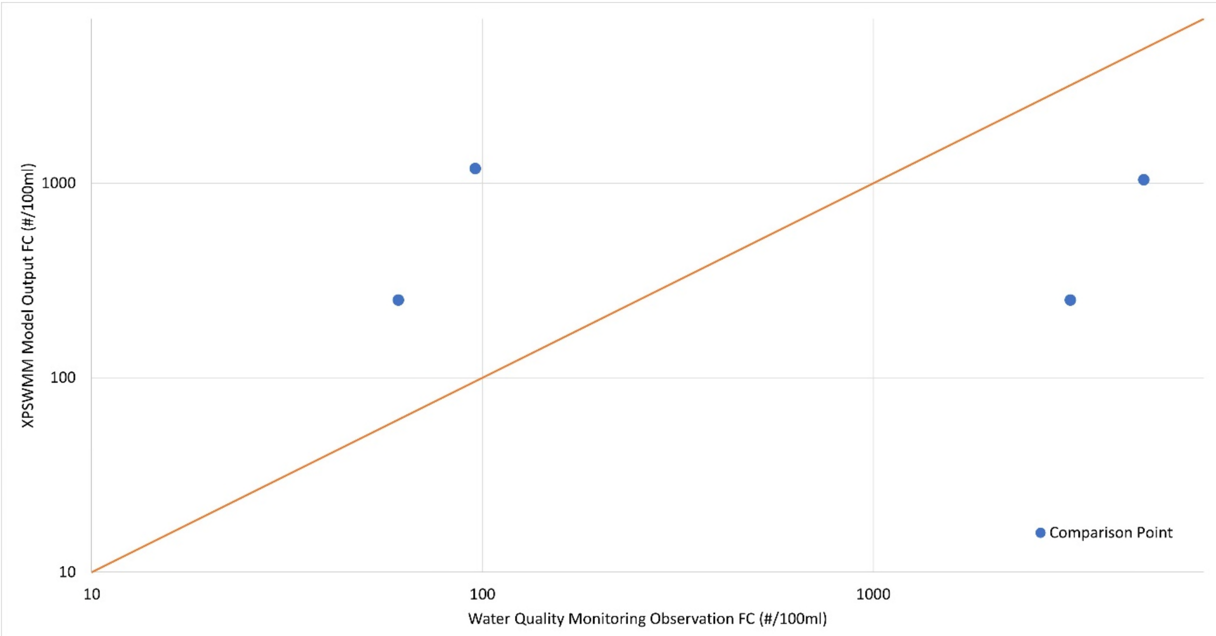

Figure 25. USGS 02176713 Observed vs. Modeled Fecal Concentrations – Baseline Conditions 2002 (Palmetto Bluff)

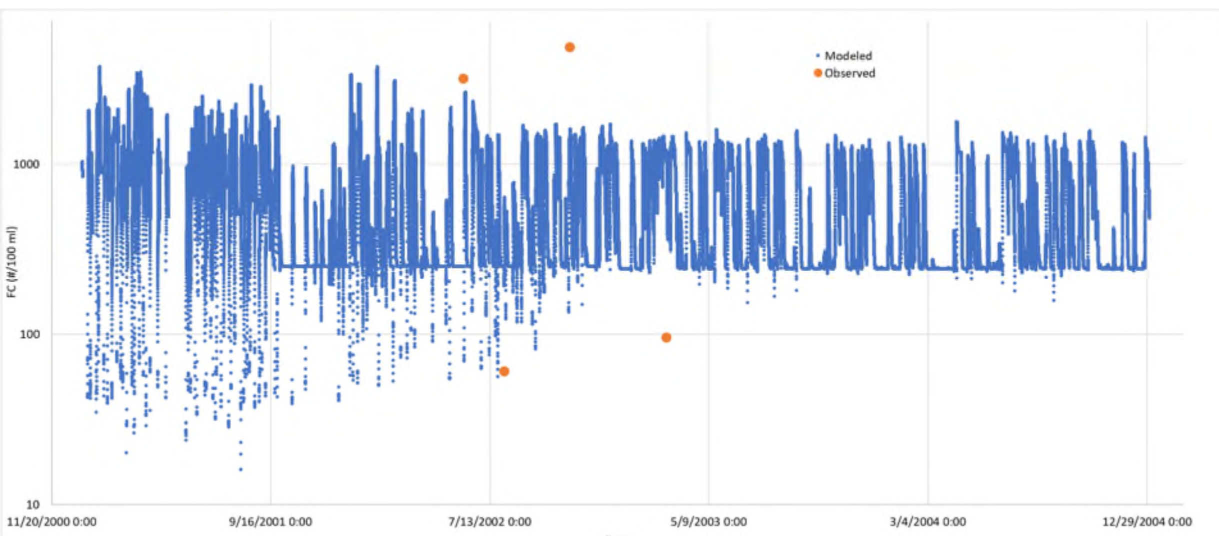

Figure 26. USGS 02176713 Observed and Modeled Fecal Concentrations – Baseline Conditions 2002 (Palmetto Bluff)

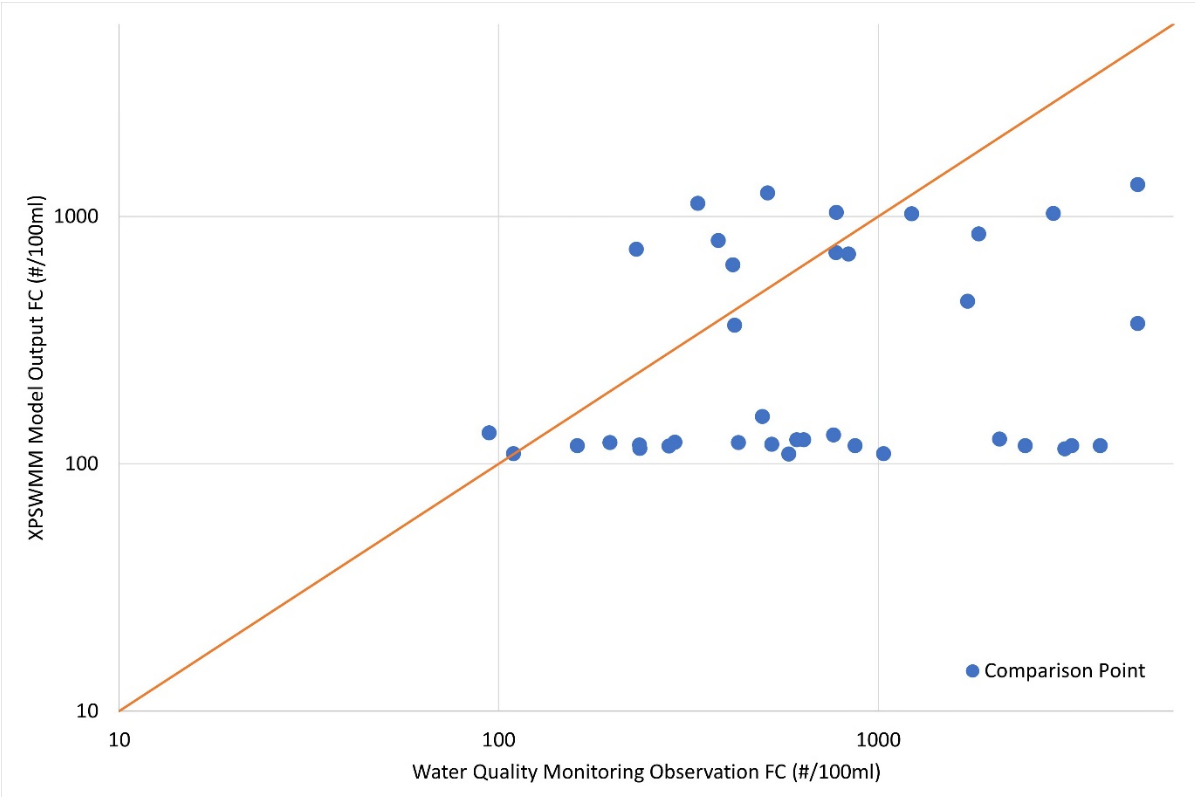

Figure 27. MRR06 Observed vs. Modeled Fecal Concentrations – Current Conditions 2018 (Rose Dhu Creek)

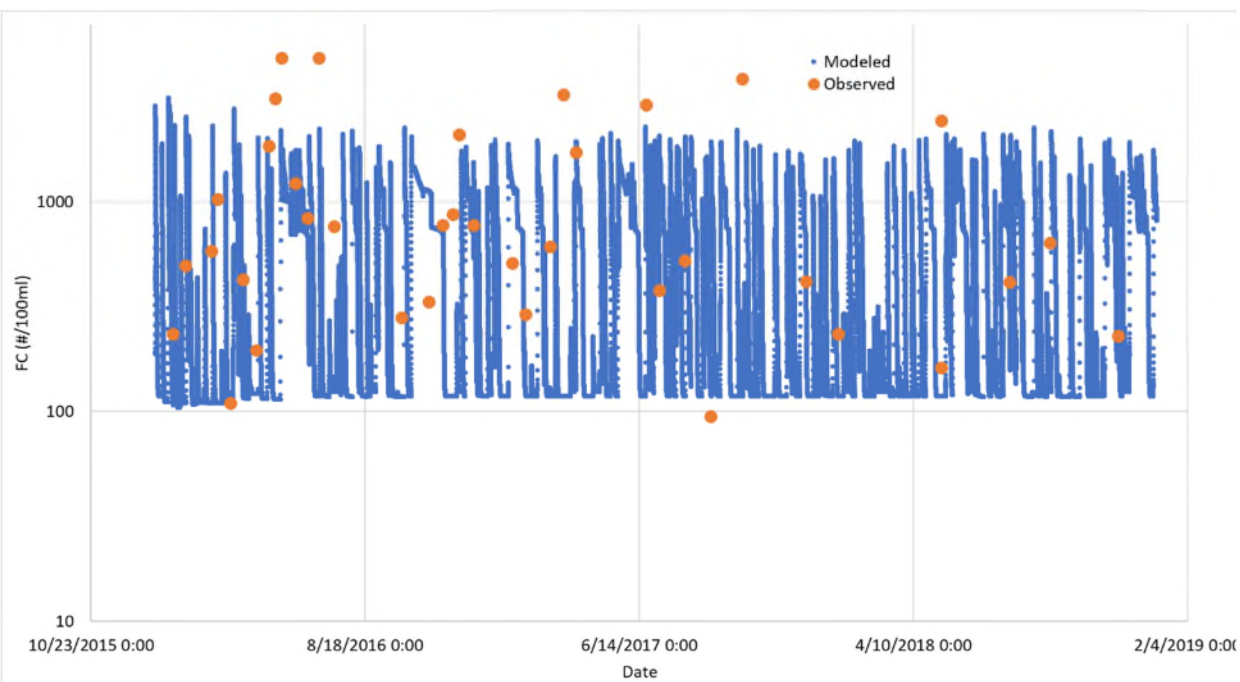

Figure 28. MRR06 Observed and Modeled Fecal Concentrations – Current Conditions 2018 (Rose Dhu Creek)

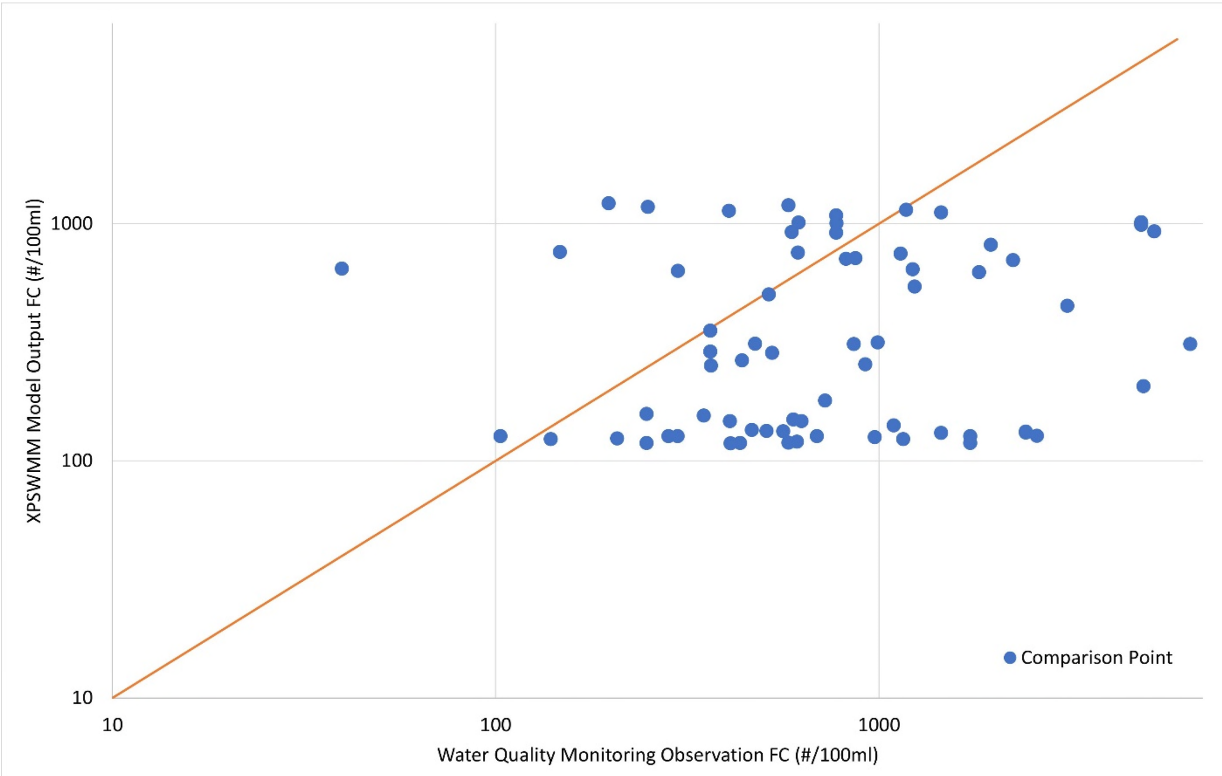

Figure 29. HH9 Observed vs. Modeled Fecal Concentrations – Current Conditions 2018 (Rose Dhu Creek)

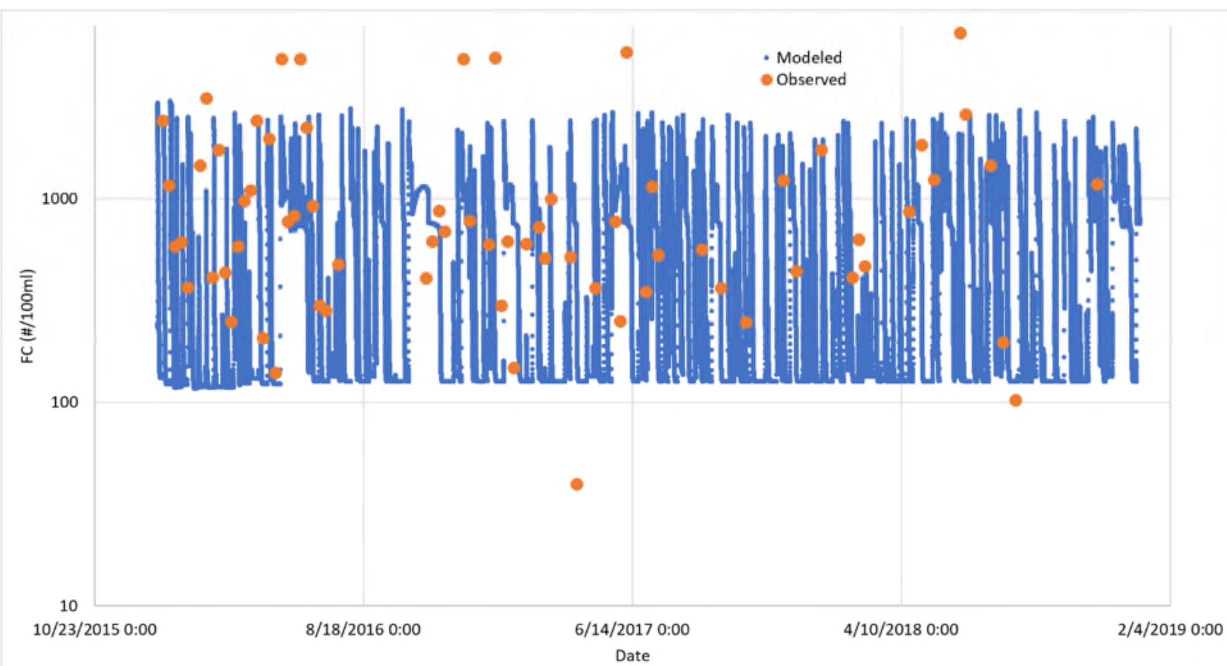

Figure 30. HH9 Observed and Modeled Fecal Concentrations – Current Conditions 2018 (Rose Dhu Creek)

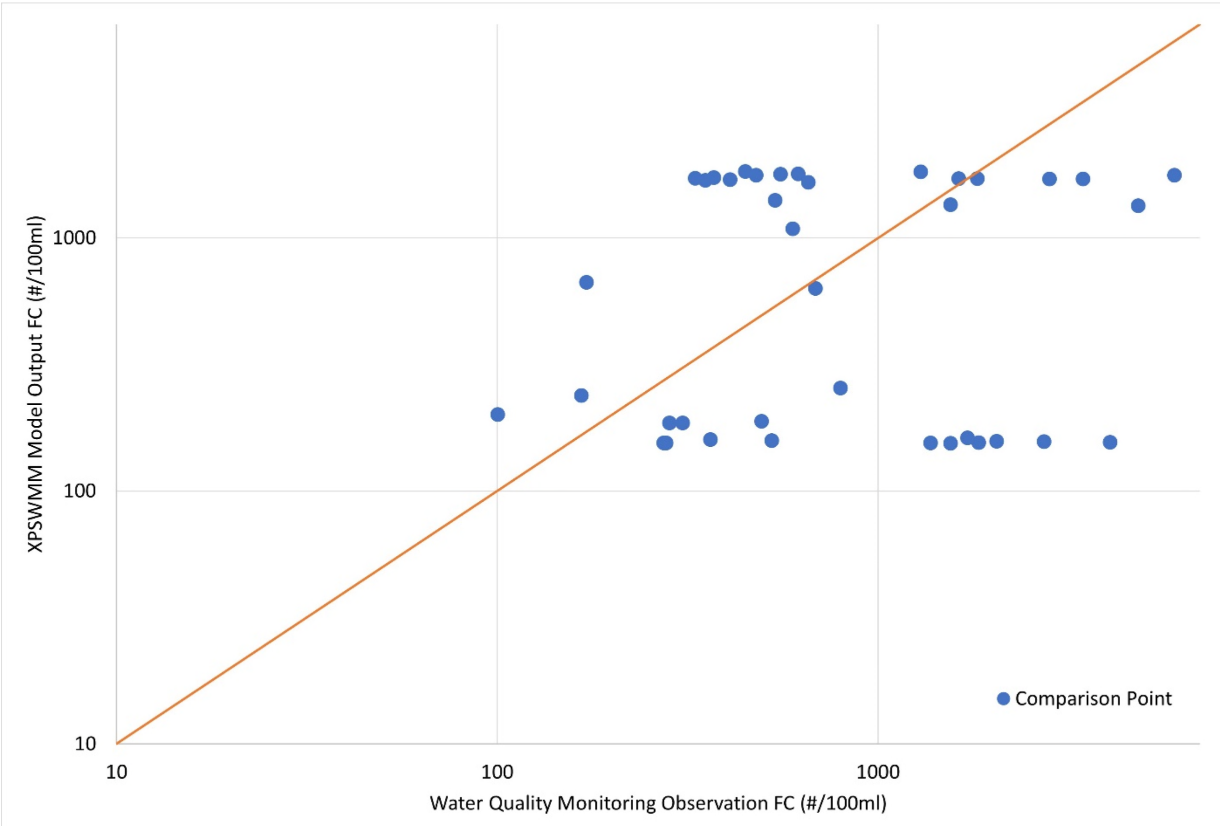

Figure 31. MRR10 Observed vs. Modeled Fecal Concentrations – Current Conditions 2018 (Stoney Creek)

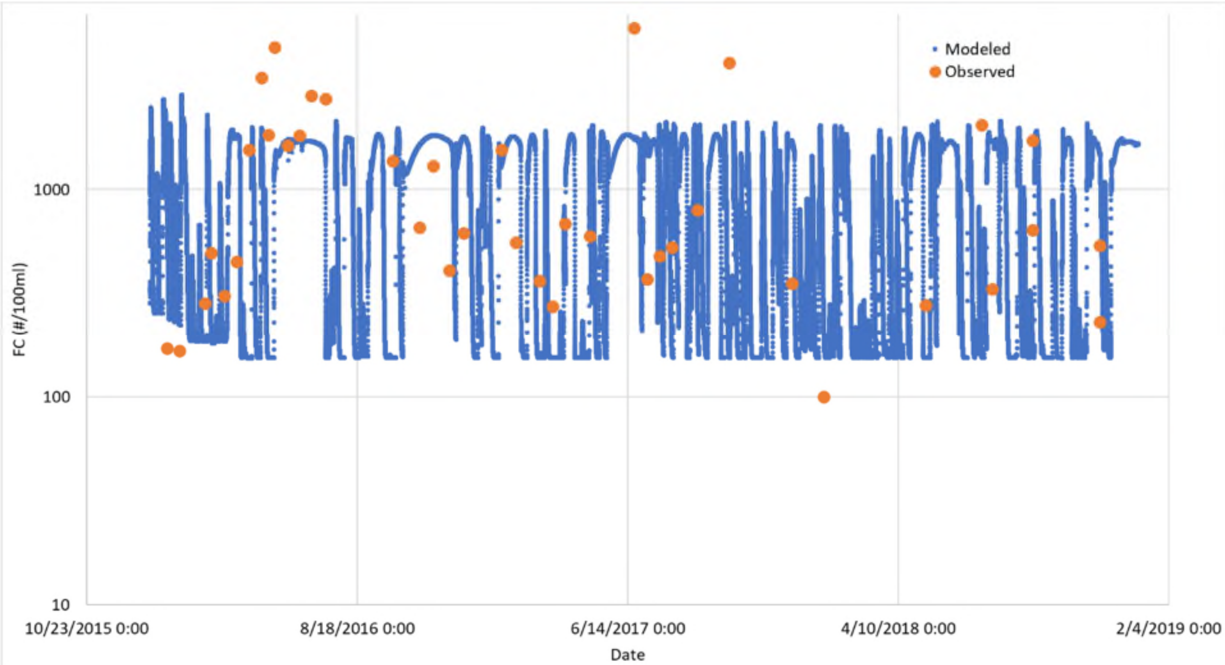

Figure 32. MRR10 Observed and Modeled Fecal Concentrations – Current Conditions 2018 (Stoney Creek)

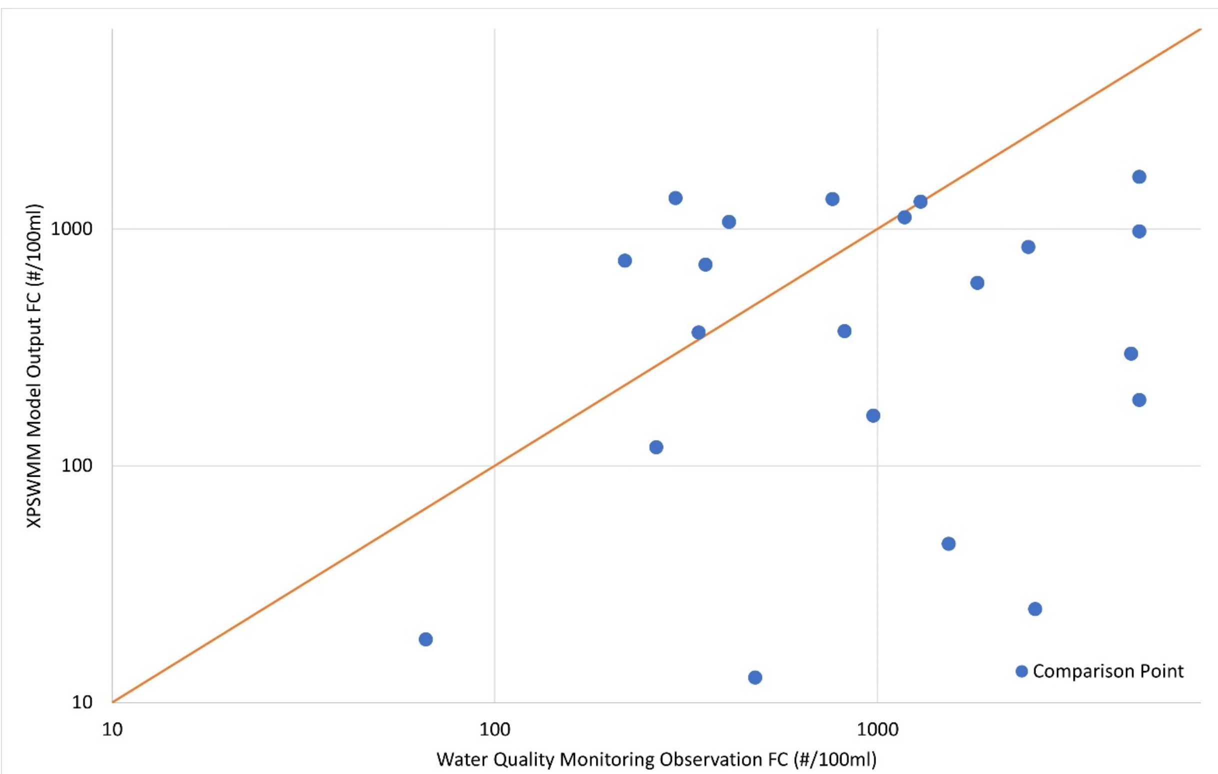

Figure 33. PBR9 Observed vs. Modeled Fecal Concentrations – Current Conditions 2018 (Stoney Creek)

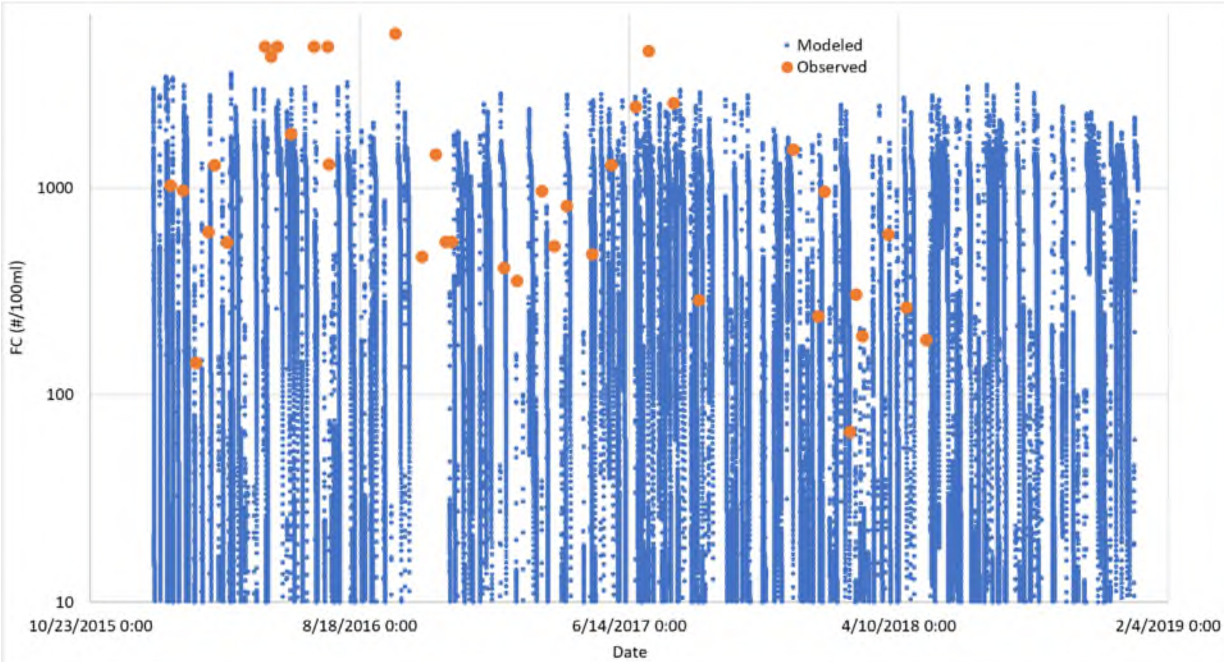

Figure 34. PBR9 Observed and Modeled Fecal Concentrations – Current Conditions 2018 (Stoney Creek)

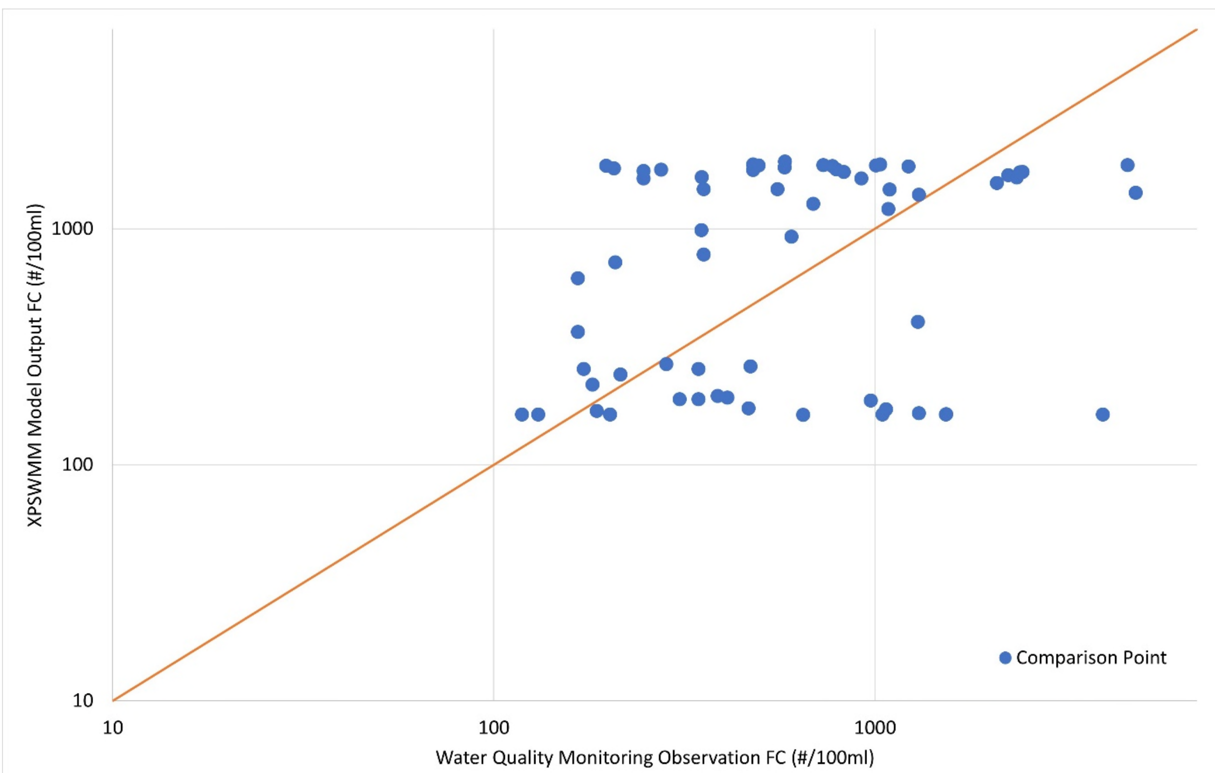

Figure 35. SC4 Observed vs. Modeled Fecal Concentrations – Current Conditions 2018 (Stoney Creek)

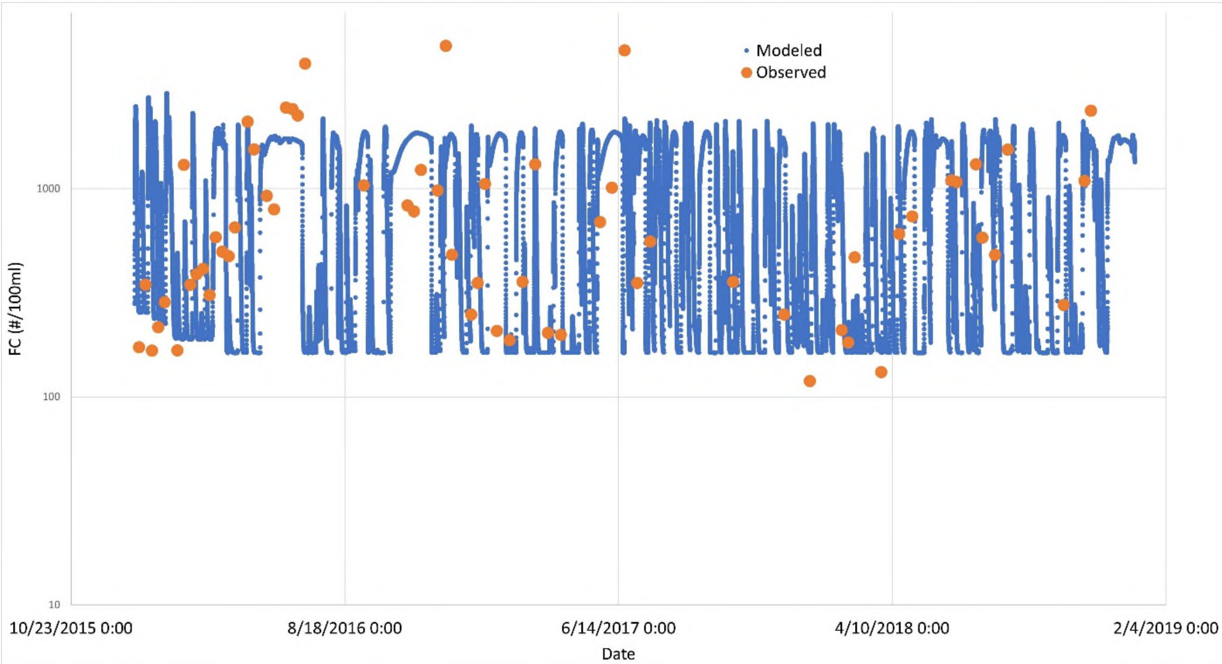

Figure 36. SC4 Observed and Modeled Fecal Concentrations – Current Conditions 2018 (Stoney Creek)

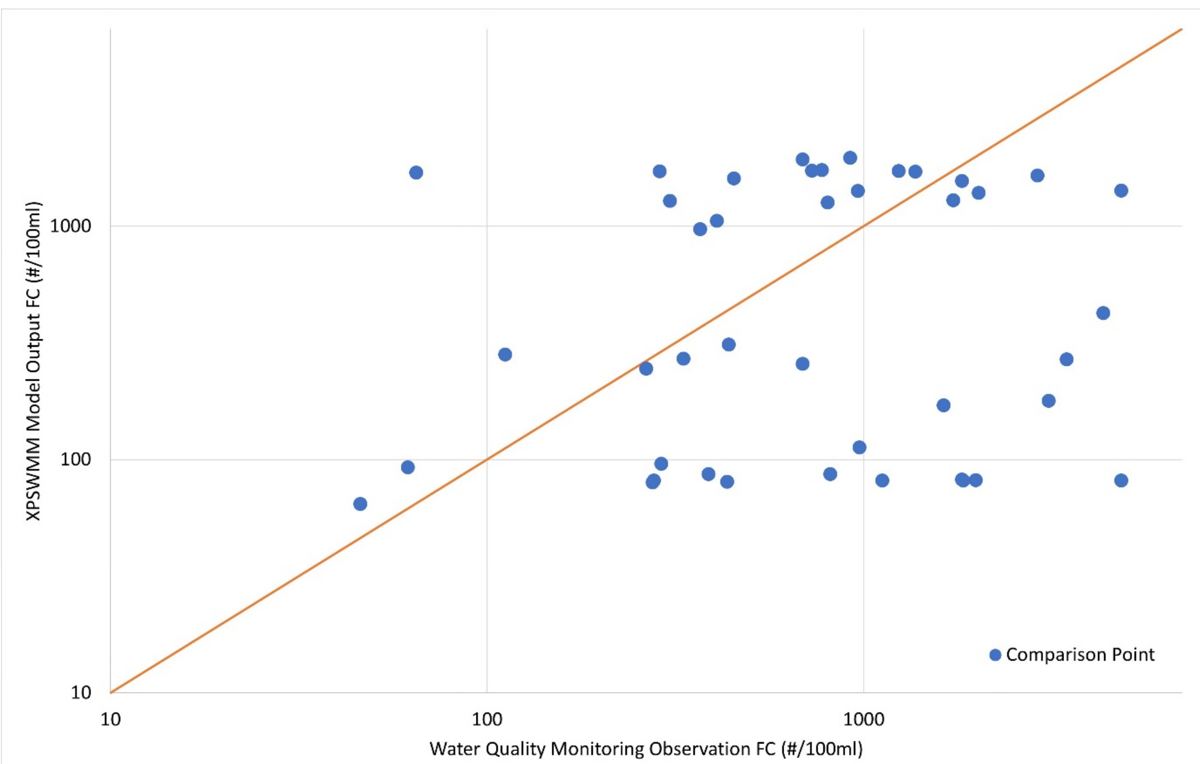

Figure 37. SC6 Observed vs. Modeled Fecal Concentrations – Current Conditions 2018 (Stoney Creek)

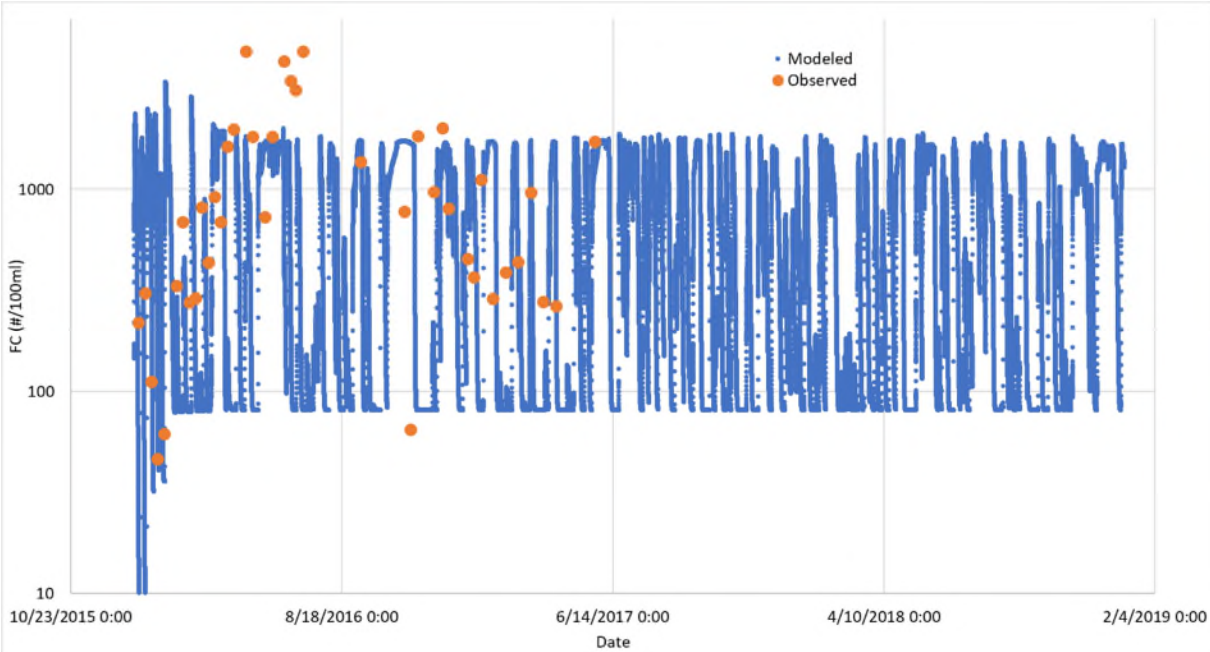

Figure 38. SC6 Observed and Modeled Fecal Concentrations – Current Conditions 2018 (Stoney Creek)

Table 34: Summary of Model Setup and Calibration Parameters

Model Input and Calibration Data	Data Gap	Assumption(s)	Recommendations for Future Work to Resolve Data Gap and Keep Model Current
Subcatchment Delineation	N/A	Subcatchment delineations did not change from 2002 to 2018; some subcatchments were aggregated for modeling purposes while maintaining appropriate level of detail.	Periodically update subcatchment delineations as data becomes available (e.g. newer LiDAR, updated stormwater infrastructure)
Channel Network	Cross-section dimensions	Used LiDAR to approximate dimensions of channels, based on drainage network GIS information provided by Town/County	Survey representative channel cross-sections for link input for the model
Channel Network	Cross-section roughness	Used aerial imagery and NLCD data to estimate Manning's roughness coefficients	Survey representative channel cross-sections and use field observations to estimate roughness
Channel Network	Channel invert elevations	Estimated from the "LevelDEM79_40" raster provided by the Town	Survey channel inverts
Impervious Cover	N/A	Data received from the Town for 2018; impervious cover for 2002 was created by removing areas from the 2018 dataset using aerial imagery and land use data	Ensure Town's database of building footprints, walkways and pathways, parking areas, driveways, roads and curbs, and ponds is current for each subcatchment
Connected/Disconnected Impervious Cover	N/A	The percentage of impervious area that is disconnected versus connected was estimated for each land use type using literature-supported disconnection fractions and previous experience/professional modeling	

Model Input and Calibration Data	Data Gap	Assumption(s)	Recommendations for Future Work to Resolve Data Gap and Keep Model Current
		judgement. The amount of connected impervious area was calculated as the total impervious area minus the disconnected impervious area.	
Precipitation	Local 15-minute data	Bennett's Point was too far away; KSAV only had hourly data and is ~20 miles from the May River watershed	Establish meteorological station in May River watershed/Town of Bluffton with capability of continuous, long-term monitoring at desired frequency
Evaporation	N/A	Calculated using meteorological data from KSAV; assumed weather at KSAV is the same as or similar to weather in the May River watershed	Update/adjust values based on changing meteorological conditions (i.e. changes in daily average temperature)
Subcatchment Parameters: area, % impervious, width, slope	N/A	Assumed accurate impervious cover and subcatchment delineation data	Update/adjust these values for the subcatchments in XPSWMM if any changes to watershed delineation and/or impervious area
Subcatchment Infiltration Parameters: depression storage, Manning's n, infiltration rates	N/A	Calculated using NLCD land use data from 2001 and 2016 and NRCS soils information	Update for changes in land use
Groundwater Parameters	N/A	Calculated using NRCS soil data, available USGS groundwater data, and SWMM guidance	Update if soils or groundwater data is updated by NRCS, USGS
Land Use	Local parcel-based land use/zoning information was not complete and	Used NLCD land use data (30 m resolution); assumed 2001 NLCD data was representative of 2002 time period,	Update for changes in land use

Model Input and Calibration Data	Data Gap	Assumption(s)	Recommendations for Future Work to Resolve Data Gap and Keep Model Current
	readily available for model use	and 2016 NLCD data was representative of 2018 time period	
Septic versus Sewer Parcels	N/A	Town septic information is representative of whether parcels utilize septic or sewer	Ensure that current septic information is accurate; update if septic/sewer information changes
Fecal Coliform EMCs	No local EMC data available	The EMCs are established for a maximum of 5 land use categories in XPSWMM; this is a limitation of the XPSWMM model—there is no ability to provide additional categories in this model; EMCs for the May River model were based on literature and adjusted to fit data.	May need to adjust or refine FC concentrations to reflect future conditions (in future the Town may discover that land use FC concentrations may shift due to policies and practices such as increased monitoring)
Local Water Quality and Flow Data	Limited flow data in the headwater subwatersheds; limited concomitant water quality and flow data	Calibration for flow was based on achieving reasonable water balance appropriate for the region and some limited comparison to flows in neighboring watersheds	Collect additional flow data at select locations both near outlets and upstream in the watershed using a cost-effective combination of continuous and instantaneous/event-based flow; also collect water quality data where possible

4.0 Water Quality Model Results

The XPSWMM water quality simulation model calculated FC concentrations for the outfalls at each of the four major subwatersheds every seven minutes for an entire year (2002 and 2018). Laboratory measurements of FC are typically given as "most probable number" (MPN) per 100/mL or as colony forming units (CFU) per 100 mL. Both units are equivalent but reflect different EPA approved methodologies for counting bacteria cells. For purposes of this report, to distinguish modeled estimates for bacteria, all results were given as "number of FC" (#) per 100/mL. In Regulation 61-68 Water Classifications and Standards, SCDHEC provides limits for FC concentrations for all water use designations. For shellfish harvesting in ORW, such as the May River, these limits are either for a daily maximum concentration (43 MPN/100 mL) or a monthly average (14 MPN/100 mL).

4.1 FC Daily Maximum Concentrations

The maximum daily FC concentration is plotted in Figure 39 (Baseline condition) and Figure 40 (Current condition). Table 35 summarizes the average of the maximum daily FC concentration for each of the subwatersheds for the entire year for 2002 and 2018. The regulated daily maximum water quality standards for shellfish harvesting (43 MPN/100 mL represented by the dotted red line in Figures 39 and 40) is provided for reference. Although the FC concentrations are generally higher in 2002 than 2018 (Table 35), the total modeled bacteria load (as will be discussed in §4.2) is lower in 2002 as a result of a very large increase in flow in 2018 (Table 36). The average maximum daily FC concentrations calculated by the model for both 2002 and 2018 consistently appear to be in excess of the shellfish water quality standard for ORW.

The Project Team also evaluated what load reduction would be required to reduce the concentrations of FC from the 2018 average conditions for Stoney Creek and Rose Dhu Creek. First, the average modeled FC concentration (FC average) for each subwatershed was calculated (average concentration = total load/total volume). For Rose Dhu Creek, the FC average was 1096.6 #/100 mL and for Stoney Creek it was 1481.8 #/100 mL. Next, the required reduction was calculated as (FC average – 43)/(FC average). This indicates that a 96.1% and 97% reduction in FC concentration is required for Rose Dhu Creek and Stoney Creek, respectively, to meet the daily maximum concentration threshold for shellfish harvesting (43 MPN/100 mL).

Table 35: Average Daily Maximum FC Concentration (#/100mL)

	Duck Pond	Palmetto Bluff	Rose Dhu Creek	Stoney Creek
2002 Baseline Condition	827	749	583	995
2018 Current Condition	538	687	650	932
Shellfish Harvesting Limit	43	43	43	43

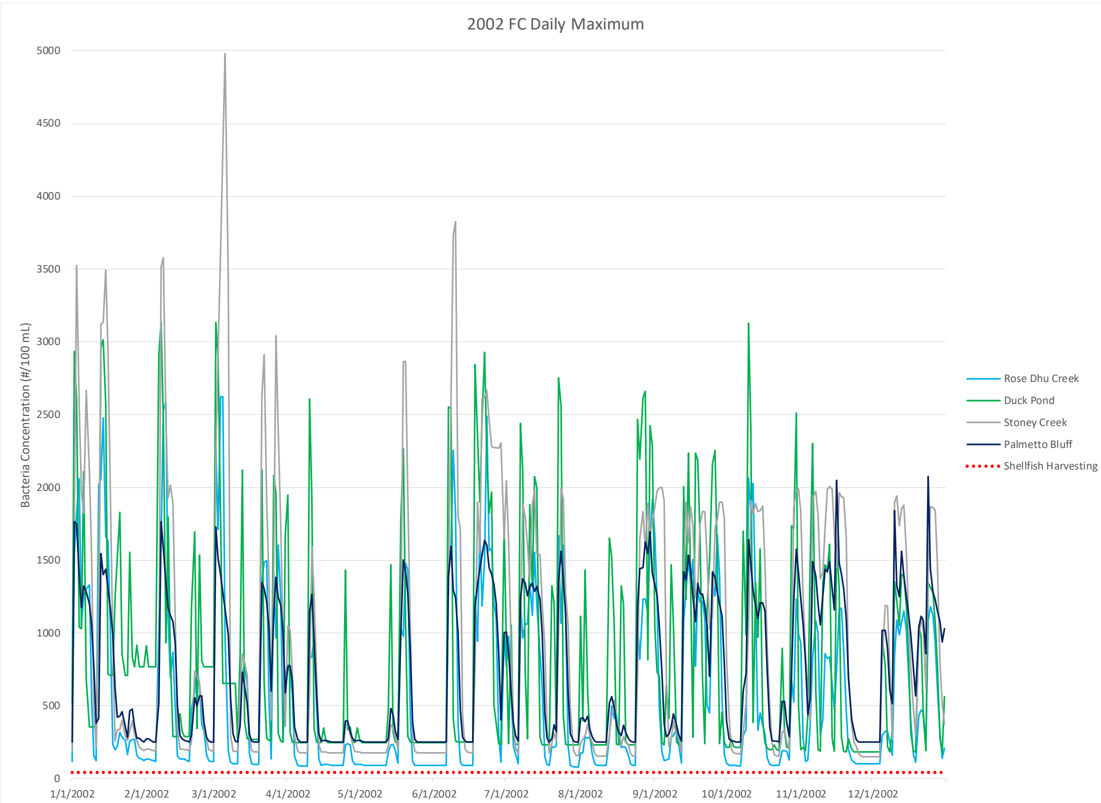

Figure 39. Water Quality Standards and Modeled Daily Maximum FC Concentrations for 2002

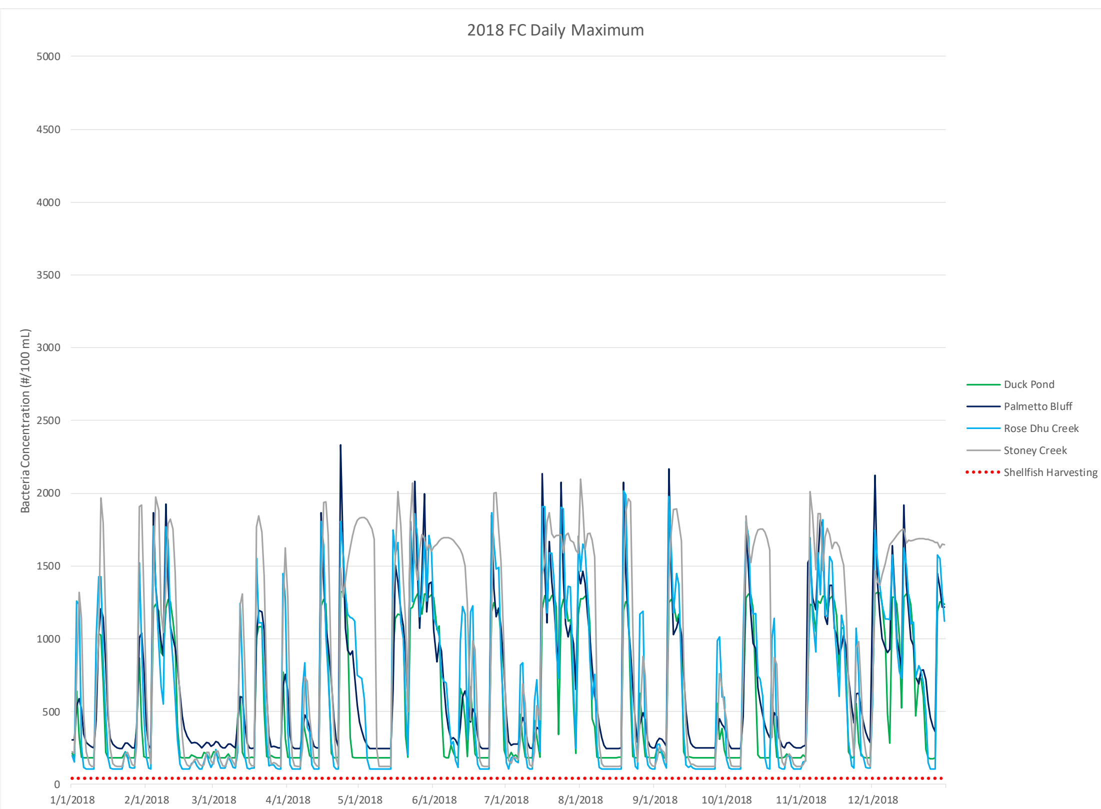

Figure 40. Water Quality Standards and Modeled Daily Maximum FC Concentrations for 2018

4.2 FC Loading

The FC load for each subcatchment in each subwatershed is calculated by multiplying the concentration by the corresponding water volume at each time step in the model. Table 36 summarizes the total annual volume of water that the model calculates exiting each subwatershed's outlet in 2002 and 2018. The volume is a combination of baseflow and stormwater runoff. Note that the total annual precipitation was 45.04 inches in 2002 and 42.95 inches in 2018; therefore, the increase in water volume in 2018 is not a result of increased precipitation, on an annual basis, but rather a result of conversion of forested land to impervious surfaces (as shown previously in Table 1, the impervious areas in the May River Headwaters have increased from 708 acres in 2002 to 1,876 acres in 2018). Impervious surfaces generate more stormwater runoff, which is reflected in the increases in water volume produced in all four subwatersheds in the May River Headwaters.

Table 36: Total Annual Water Volume at Each Subwatershed Outlet

Subwatershed	Baseline 2002 (ft^3)	Current 2018 (ft^3)	% Increase
Duck Pond	5,406,495	66,434,813	1,129%
Palmetto Bluff	38,830,300	182,059,967	369%
Rose Dhu Creek	31,131,373	450,413,444	1,347%
Stoney Creek	105,883,853	540,149,533	410%
Total	181,252,021	1,239,057,757	584%

4.2.1 Total Load Per Subcatchment

One way to evaluate the modeling results is to look at the total annual load (number of FC bacteria) the model estimates for each subwatershed for the 2002 and 2018 condition, as summarized in Table 37. The Stoney Creek subwatershed had the greatest FC load in 2002 and 2018. Table 37 also summarizes the minimum, maximum, and average loads calculated for each subcatchment within the four main subwatersheds. In 2002, Stoney Creek had the subcatchment with the greatest FC load and the average overall FC load was greatest in Stoney Creek subcatchments. In 2018, Rose Dhu Creek had the largest subcatchment load and average load. In general, the total FC load for each subwatershed, as well as the average subcatchment load, increased by one to two orders of magnitude from 2002 to 2018. This model output is supported by an analysis of SCDHEC monitoring data from 1999 to 2017 in the May River (Montie et al., 2019) which found that fecal coliform levels at SCDHEC monitoring locations closest to the Headwaters were well above the approved FC maximum of 14 MPN/100 mL (geometric mean per R61-68). Additionally, the data showed that fecal coliform levels were higher when salinity levels were lower, and this relationship is strongest at SCDHEC sampling stations closest to the Headwaters. Finally, fecal coliform levels in the Headwaters increased as population levels grew in the Town of Bluffton, and this relationship was strongest at SCDHEC sampling stations closest to the Headwaters.

Figures 41 and 42 illustrate the increase in bacteria loading from 2002 to 2018 for the May River Headwaters subwatersheds. Areas with darker red shading indicate a higher total FC load. In both 2002 and 2018, the subcatchments with the darker shading (higher load) are located within Stoney Creek and Rose Dhu Creek subwatersheds.

Table 37: Total Annual Loading (# FC/year) by Subwatershed

	Duck Pond	Palmetto Bluff	Rose Dhu Creek	Stoney Creek
2002 Baseline Condition:				
Total Subwatershed Load	1.78E+12	1.26E+13	6.79E+12	**4.93E+13**
Min Subcatchment Load	3.43E+09	6.32E+08	1.58E+09	0.00E+00
Max Subcatchment Load	8.45E+11	2.90E+12	2.02E+12	**1.26E+13**
Avg Subcatchment Load	2.96E+11	4.51E+11	3.23E+11	**8.80E+11**
2018 Current Condition:				
Total Subwatershed Load	2.18E+13	5.84E+13	1.48E+14	**2.47E+14**
Min Subcatchment Load	0.00E+00	5.67E+10	1.20E+11	1.25E+11
Max Subcatchment Load	7.79E+12	7.89E+12	**3.09E+13**	2.51E+13
Avg Subcatchment Load	3.63E+12	2.08E+12	**7.05E+12**	4.41E+12
Values in bold represent the largest value for each condition				

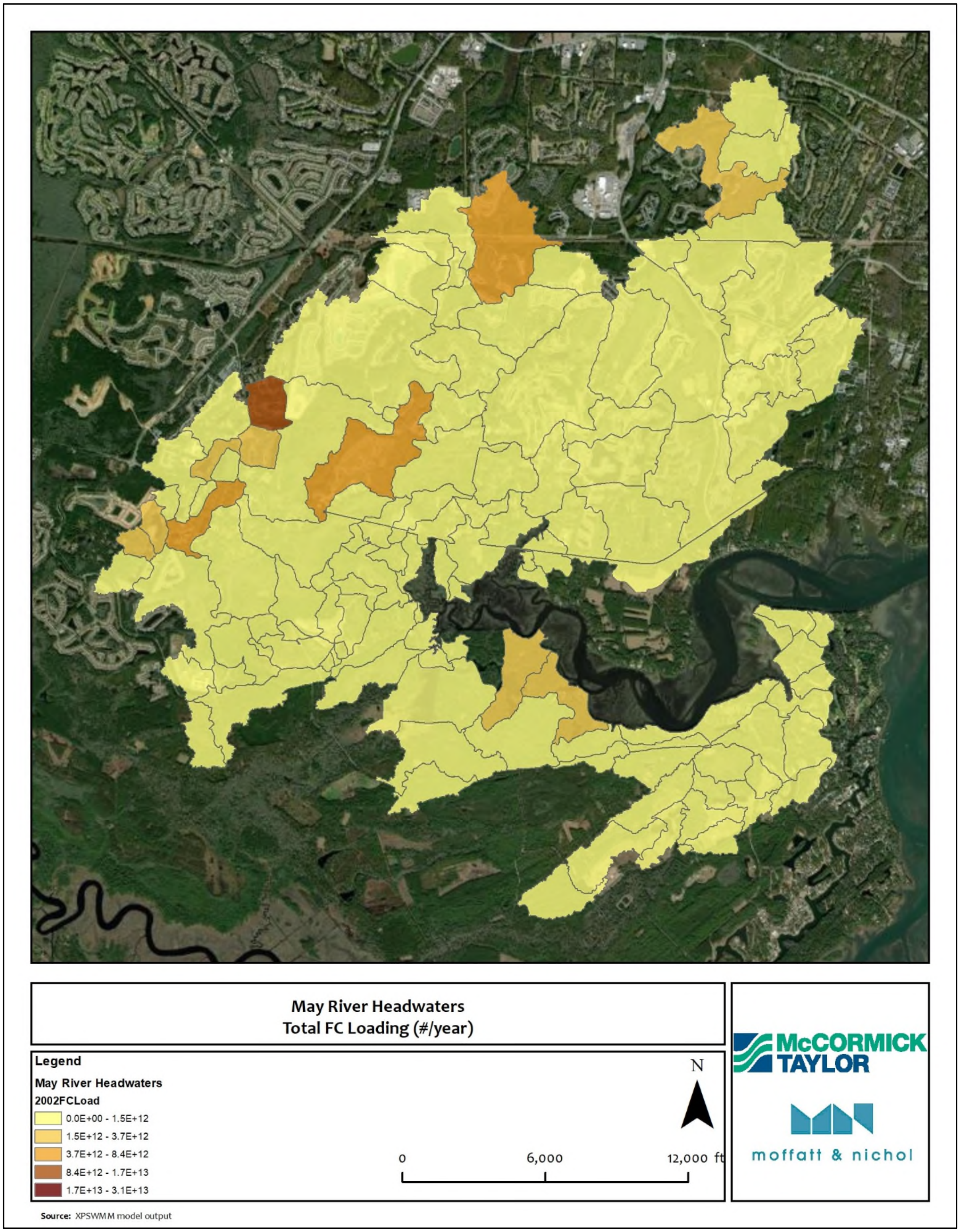

Figure 41. Total Bacteria Load of each Subcatchment in 2002 condition

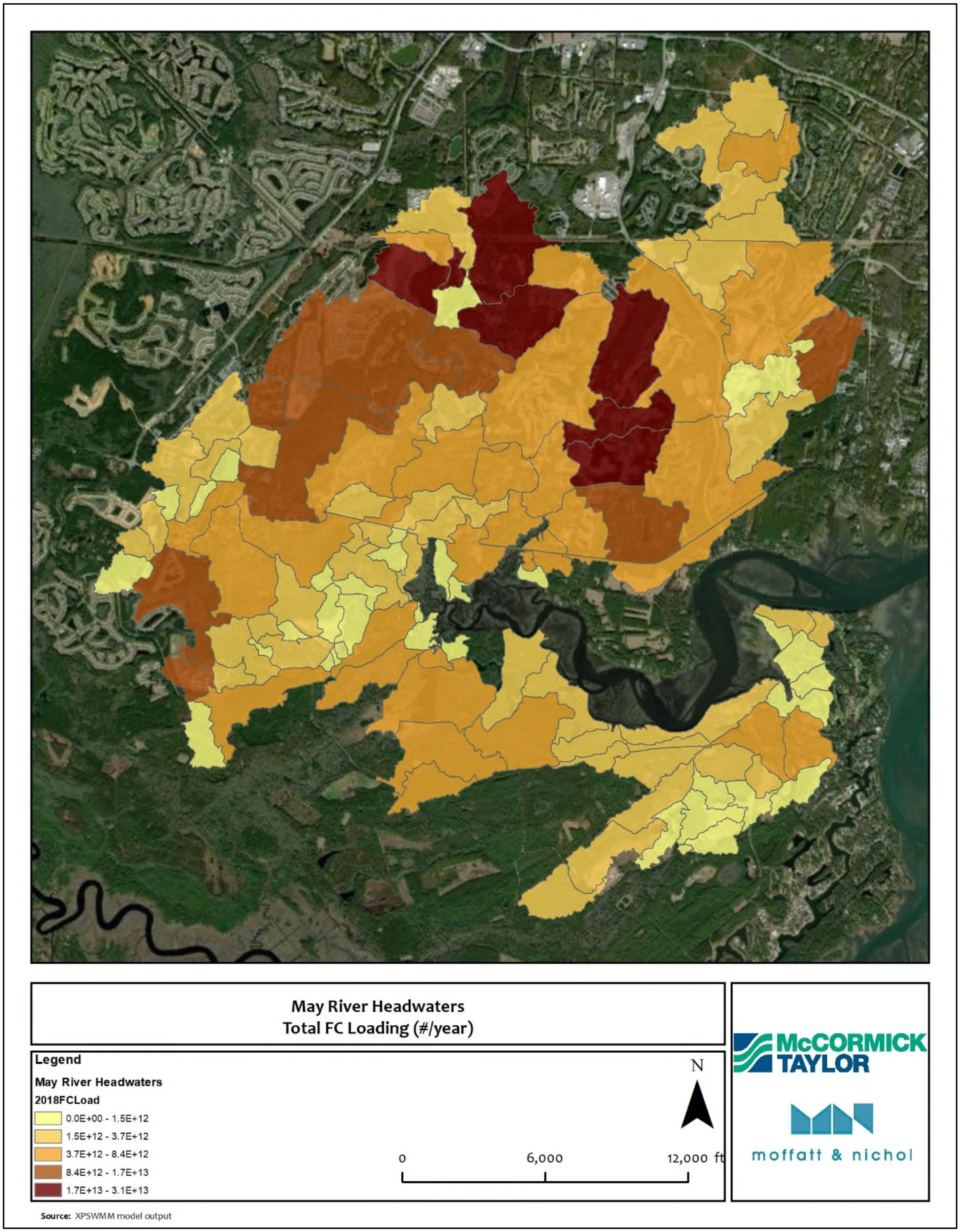

Figure 42. Total Bacteria Load of each Subcatchment in 2018 condition

4.2.2 Normalized Load Per Subcatchment

An additional way to interpret the modeling results is to calculate how much bacteria is generated per acre in each subcatchment, which allows for comparisons between subcatchments of varying sizes (Table 38, Figures 43 and 44). A large subcatchment may produce a larger overall total load than a smaller subcatchment; however, the amount of bacteria generated per acre in each could be equivalent. These normalized loads were calculated by dividing the modeled load of bacteria for each subcatchment by its respective area in acres. In 2002, the normalized loading for all four subwatersheds was at the same order of magnitude. Rose Dhu Creek had the lowest total normalized load for the entire subwatershed (1.63E+09 FC/acre) and Stoney Creek had the highest (9.18 E+09 FC/acre). Comparing subcatchments, Stoney Creek had the smallest minimum value (0 bacteria/acre), the largest maximum value (1.96 E+11 FC/acre), and the largest average value (1.55 E+10 FC/acre). Note that monitoring data from various agencies report FC concentrations (#/100 ml) and not loads, and there are no other published load data to compare with the results of this model.

In 2018, the normalized loading for all four subwatersheds was at the same order of magnitude; however, the totals were also ten times higher (one order of magnitude greater) than in 2002. Once again, Stoney Creek had the highest maximum and average normalized loading in a subcatchment. Duck Pond and Palmetto Bluff had the lowest normalized loadings at both the subwatershed and subcatchment level for all categories (total, min, max, and average).

Table 38: Normalized FC Loading (#/acre) by Subwatershed

	Duck Pond	Palmetto Bluff	Rose Dhu Creek	Stoney Creek
2002 Baseline Condition:				
Total Subwatershed	2.60E+09	6.55E+09	1.63E+09	**9.18E+09**
Min Subcatchment	1.05E+08	5.66E+07	1.02E+07	0.00E+00
Max Subcatchment	4.78E+09	6.64E+10	9.69E+09	**1.96E+11**
Avg Subcatchment	2.05E+09	8.33E+09	1.68E+09	**1.55E+10**
2018 Current Condition:				
Total Subwatershed	3.19E+10	3.03E+10	3.55E+10	**4.61E+10**
Min Subcatchment	0.00E+00	9.99E+08	5.14E+09	1.62E+10
Max Subcatchment	4.77E+10	9.84E+10	1.25E+11	**1.95E+11**
Avg Subcatchment	2.67E+10	3.48E+10	3.69E+10	**5.01E+10**
Values in bold represent the largest value for each condition				

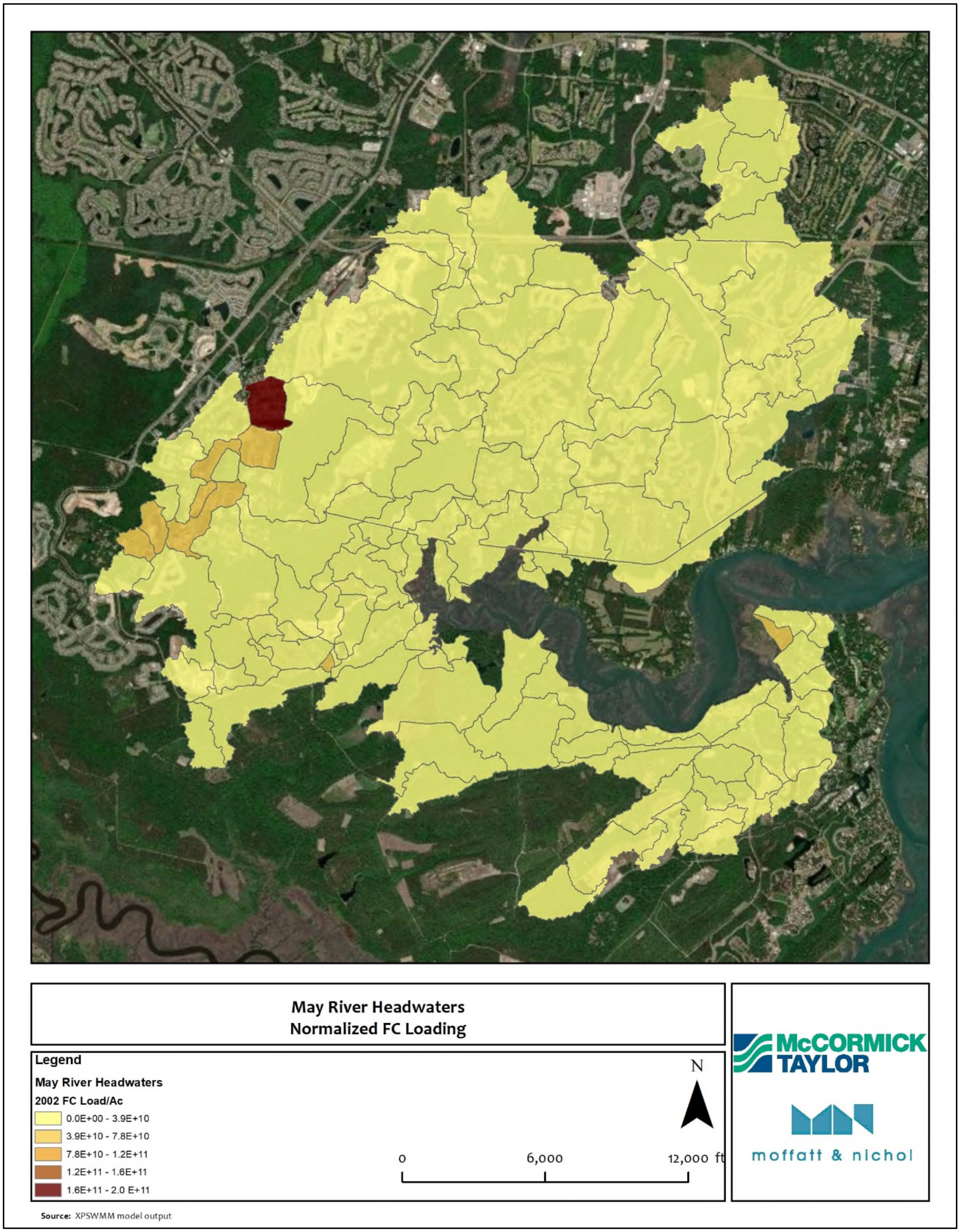

Figure 43. Bacteria Load per Acre of each Subcatchment in 2002 condition

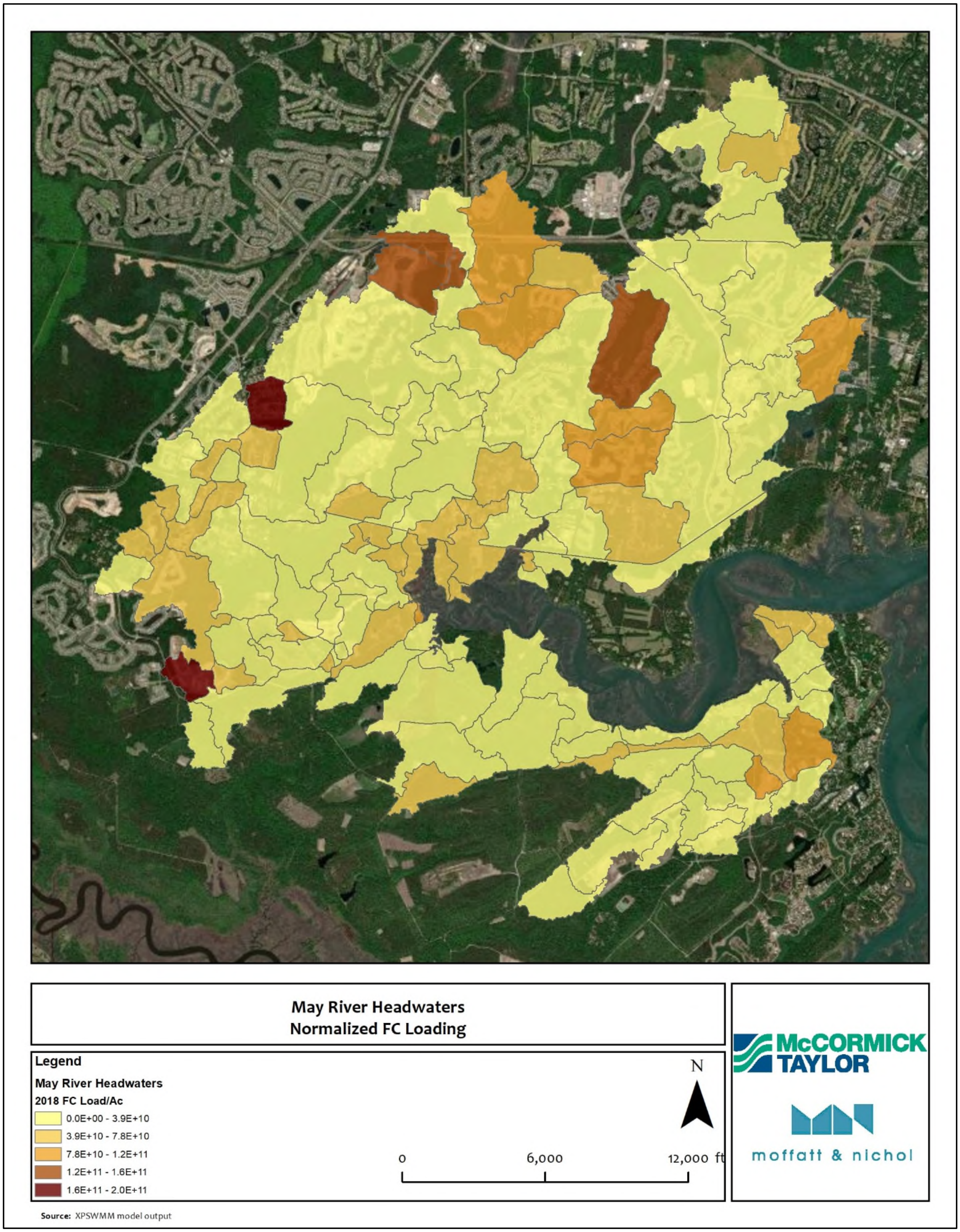

Figure 44. Bacteria Load per Acre of each Subcatchment in 2018 condition

4.2.3 Bacterial Hotspots

Table 39 summarizes the ten subcatchments that had the highest overall annual FC loading in the May River Headwaters. All of the highest loads are found in subcatchments in the Stoney Creek or Rose Dhu Creek subwatersheds, and all were the same order of magnitude (10^{13}). Data from an existing monitoring station (HH9) is located near the SUB-RD-11 subcatchment and was used for calibrating the model (refer to Figures 25 and 26 in Section 3.2). Note that SUB-RD-09 and SUB-RD-11 (shaded gray) are included in all three lists for priority ranking based on bacteria load: overall, normalized, and rate of increase, Tables 39 – 41, respectively.

Table 39: Highest 2018 FC Load

Subcatchment	Development Phase	Area	2018 IA (acres)	IA %	FC Load (# FC)
SUB-RD-09	Hampton Hall 4, IA, IB	247.10	50.48	20%	3.09E+13
SUB-RD-11[a]	Hampton Hall 2, 4A, CA, GC, I-B, I-C,	292.79	29.75	10%	2.66E+13
SUB-RD-17	Hampton Hall 2, 2A,-2, 2B-1, 2C, 2D, CA, I-B, I-C,	292.79	76.46	26%	2.66E+13
SC106	Hampton Lake 1, 1B, 1B-1, 2, 3 Baynard Park 2	260.56	54.48	21%	2.51E+13
SC103	Hampton Lake 4, 7, 8A, 8B	157.29	6.58	4%	2.17E+13
SC108	Hampton Lake 4	157.29	12.39	8%	2.17E+13
SC112	Hampton Lake 1, 1B, 1B-1, 2	201.66	58.95	29%	2.06E+13
SC116	Lawton Station 1, 3, 3C, 4C, Hampton Lake 1A, 1C, 2, 2B, 2C, 3, 3C, 5, 6, 11, Lake Estates	741.45	163.72	22%	1.71E+13
SC162	Hampton Lake 1, 1A	741.45	59.92	8%	1.71E+13
SUB-RD-12	Pinecrest 3, 4, 5, 6, 7, 8	155.28	34.38	22%	1.64E+13
[a] Located near station used for calibration (HH9)					

The subcatchments with the highest normalized FC loading are listed in Table 40. Note that SC103, 106, and 112 are listed on both Table 39 and 40.

Table 40: Highest 2018 Normalized FC Load

Subcatchment	Development Phase	Area	2018 Impervious Area (acres)	Impervious Area %	FC Load (#/acre)
SC142	May River HS	60.72	23.58	39%	1.95E+11
SC124	(county)	64.47	19.39	30%	1.83E+11
SC104	Hampton Lakes 8B Bluffton Pkwy	49.46	7.37	15%	1.47E+11
SC103	Hampton Lake 4, 7, 8A, 8B	157.29	6.58	4%	1.38E+11
SC108	Hampton Lake 4	157.29	12.39	8%	1.38E+11
SUB-RD-09	Hampton Hall 4, IA, IB	247.10	50.48	20%	1.25E+11
SUB-RD-12	Pinecrest 3, 4, 5, 6, 7, 8	155.28	34.38	22%	1.06E+11
SC112	Hampton Lake 1, 1B, 1B-1, 2	201.66	58.95	29%	1.02E+11
PB17	Palmetto Bluff Village	35.30	2.18	6%	9.84E+10
SC106	Hampton Lake 1, 1B, 1B-1, 2, 3 Baynard Park 2	260.56	54.48	21%	9.62E+10

Table 41: Highest FC Load Rate of Increase

Subcatchment	Development Phase	2002 FC Load	2018 FC Load	Rate of Increase
SC125[a]	(county)	2.18E+06	2.59E+12	1,189,492
SUB-RD-12	Pinecrest 3, 4, 5, 6, 7, 8	1.58E+09	1.64E+13	10,366
SC158	No PUD	4.15E+08	1.76E+12	4,233
SC159	Palmetto Bluff	4.15E+08	1.76E+12	4,233
SC129[b]	New Riverside (Parcel 9)	1.97E+09	2.78E+12	1,410
SUB-RD-01	Buckwalter PUD	3.89E+09	3.72E+12	956
SUB-RD-09	Hampton Hall 4, IA, IB	3.51E+10	3.09E+13	879
SC155	New Riverside (Parcel 9)	1.87E+09	1.12E+12	599
SUB-RD-07	Buckwalter PUD	2.92E+09	1.59E+12	544
PB27	Palmetto Bluff Ph 1, Palmetto Bluff Village	1.82E+10	7.89E+12	432

[a] Located near station used for calibration (SC6)

[b] Located near station used for calibration (PBR9)

5.0 Recommendations

5.1 Strategies for Assessing Problems (Monitoring, Mitigation, and Modeling)

The Project Team provides the following suggestions for the Town of Bluffton to improve upon their existing monitoring program for bacteria (concentration and source typing) and flow.

5.1.1 In-House Microbial Source Tracking

The Town of Bluffton has purchased equipment and supplies that allows them to conduct advanced quantification of molecular fecal markers to identify sources of fecal contamination in environmental waters. The system is a quantitative polymerase chain reaction (qPCR) system from Bio-Rad. The system allows the quantifications of bacterial and viral pathogens as well as molecular markers. Quantifying and identifying these markers can be used in monitoring and experimental studies to understand the dispersion, quantity, and any reductions of fecal contamination to the Town of Bluffton systems to facilitate in-house qPCR for source typing. Dr. Rachel Noble provided guidance for implementation of molecular approaches for microbial source tracking (MST) based assessments in a memo dated June 10, 2020 (Appendix B) and summarized in the below recommendations. Dr. Rachel Noble is available to work with the Town of Bluffton to develop their capacity for this type of work, to train the Town personnel in the use of the equipment following standardized procedures and controls, and to implement the quantitative testing in specific areas for prioritization of water quality management scenarios.

Recommendations for Town of Bluffton:

1. Combine the benefits of new technological advancements for the combination of geographic information system approaches, traditional fecal indicator bacteria monitoring, and quantification of molecular markers of specific sources of fecal contamination (Li et al. 2019).
2. Focus on the use of multiple, coincident, molecular library-independent markers of human fecal contamination first. An approach to use multiple fecal *Bacteroides* based markers such as HF183 in addition to the newly published sewage-associated *Bacteroides* marker (Feng et al. 2019) to identify, quantify and confirm the likely incidence of human fecal contamination across sites (e.g. Hart et al., 2020). The combined application of HF183 and the sewage-associated marker can be high utility tools that would allow the Town to not only quantify human fecal contamination in the system, but confirm its source from sewage infrastructure, permitting additional infrastructure testing to take place.
3. The Town could consider the quantification of human pathogenic markers such as adenovirus or enterovirus to quantify human viruses that are very specific to the presence of human contamination (Steele et al., 2018). The human viruses also provide important information as to the presence of "fresh" fecal contamination, because they are not likely to persist in the stormwater and receiving water environments for long periods of time. In particular, it may be useful to pair quantification of human pathogens to existing monitoring approaches, given the concept that reservoir populations of FIB are contributing to overall loading. USEPA is considering standardization of microbial source tracking approaches that permit States to assess the potential for natural sources of both Enterococcus sp. and fecal coliforms, if they can be demonstrated using scientifically credible approaches (Boehm et al. 2015).

4. Use a "tracer screen" approach. At first, based upon localized results, it is recommended that the Town should incorporate HF183 and BacHum into stormwater assessments. Use human adenovirus quantification for the human pathogenic virus because of its relevance in the southeast. Use the qPCR assay for *Catellicoccus marimammalian* to quantify bird fecal contamination. Analyze at least 10 sewage influent and 8 scat fecal samples (from each species) to characterize the utility of animal markers. If the area of interest is dominated by septic systems and package treatment plants, it may be fruitful to capture a composite sample from septic system distribution boxes if possible. Conducting the repeat sample analysis will allow the Town to assess the true cross-reactivity, sensitivity and specificity of each applied marker. For viral pathogens, it also allows assessment of the seasonal nature of specific molecular targets (Steele et al. 2018). It is far better to devote attention to doing the work up front to assess specificity of markers rather than to worry about cross reactivity later in the project. For example, in FL, the HF183 marker cross reacts with deer fecal contamination across most of the aquatic systems, causing a low level of HF183 to be quantified across the landscape, but with little relationship to the presence of human fecal contamination. Without repeat assessment of known fecal sources with markers of specific types of contamination, these patterns would have never been revealed. The fecal markers that are recommended at first for assessment are DogBact. A review of the literature is taking place to assess the best ruminant markers and canine markers, but at this time, most of them still have serious cross reactivity issues.
5. Pay close attention to sample design issues, following the lead of well-designed previous studies by sampling over a wide array of events, monthly sampling with additional focus on wet weather events (>0.5" precipitation over a 24 hour period (Gonzalez et al. 2014; Hart et al., 2020)). Use statistically rigorous approaches and quantify samples across enough events to ensure confidence in the results. It is optimal to collect samples during or immediately after the rainfall event, with attention paid to tidal cycle (low to mid-tide is typically suggested for low-lying coastal systems).
6. To determine whether a stormwater system contains human fecal contamination, you need a sampling design that permits the science to 1) statistically defend negative results, and 2) interpret heterogeneity in storms. For the first, there must be a plan in place that allows the researcher to defend negative or "non-detect" results in a system. For the qPCR analysis of molecular markers for water quality management, consider 11 repeat sampling events to be the minimum level of statistical rigor, i.e. with 11 sampling events over the course of 11 storms, expecting a positive response rate of 10% for any one of the measured markers, you would have an 90% confidence that the results reported were correct within a 15% +/- confidence interval. As the sample size increases, of course, the confidence in interpreting the results (i.e. increased sampling effort increases confidence) increases. This 90% confidence is likely acceptable for this study. Furthermore, this is expecting only a 10% "response rate" for the tests. As the test response rate increases, there is actually a need for greater number of sampling events to preserve the confidence interval. However, given that the question posed for this project, is focused on whether the fecal contamination is human, the statistical attributes of this power analysis are correct. As confidence decreases (as sampling effort decreases), one decreases their ability to have confidence when only negative results are observed, thereby lowering the confidence in the results. For any qPCR data to be considered as quantitative, remember that appropriate controls must be used to avoid false-negative or false-positive results. For example, using a no-template control allows the researcher to assess the potential for cross contamination stemming from poor lab practices (false positive). Conversely, it is necessary to always use an inhibition control and an extraction control to

verify that the procedures are working, so as to avoid false negatives. A full set of guidelines for qPCR reporting can be found at Bustin et al. 2009.

7. MST marker assessments for stormwater are dependent upon a wide range of conditions being assessed over the course of your study. In sequence, the character of discharge from linked storms are dependent upon one another and antecedent rainfall and the delivery of rainfall are extremely important to microbial loading patterns. This is the justification for not sampling only across one or two storms, but instead a wide range of storm conditions over time to determine whether human fecal contamination is being delivered and if so, if multiple succession storms show a human fecal contamination pattern. Sampling throughout the duration of storms can provide very valuable information by understanding discharge patterns that are dominated by landscape delivery (early in the storm) or groundwater influx (delivery during the tail end of the storm).
8. Dry weather sampling should be conducted as a part of any implementation of molecular analyses for MST markers. The reason is that many groups have detailed important changes or construction to be conducted after wet weather sampling, but in some cases, the signal would have persisted there even during dry weather, showing that the signal is not stormwater dependent. For baseline sampling, a repeat analysis of at least 5 different time periods is required to assess the presence of human fecal contamination in the system in the absence of rainfall. This is the minimum baseline sampling required to rule out the dry weather human fecal contamination influence.
9. Use a weight of evidence approach for your results interpretation. When results interpretation involves a weight of evidence approach, there is no one marker that stands alone in the determination of human fecal contamination. This allows decision making at the infrastructure, BMP and policy making to be more robust. A typical scheme might be to confirm human fecal contamination only with repeat quantification of both HF183 and BacHum through multiple storms in order for infrastructure changes to be recommended (e.g. Hart et al. 2020). When incorporating human viral pathogens into your interpretation scheme, make certain that controls are in place to ensure that all quantification is occurring, and that the controls are being implemented at concentrations that are relevant to risk associated with sewage-based sources of pathogens.
10. It can be valuable to incorporate the use of predictive modelling approaches such as those observed in the literature previously. Multiple linear regressions modelling approaches that take into account data collected for FIB, molecular markers of fecal sources, environmental parameters (Gonzalez et al. 2014), and even elevation and tidal influence are highly valuable to understanding the drivers of stormwater movement in the estuarine system.

5.1.2 Future (new) Bacteria Monitoring Locations

The results from the water quality model could be improved upon if an increased amount of fecal indicator bacteria, MST, and pathogen data were available in these areas of the watersheds. Unfortunately, using the fecal indicator bacteria approach has its limitations for understanding risk in the receiving water environment. For example, once analysis of multiple classes of microbial contaminants takes place, the manager can create linear models to compare HF183, E. coli, fecal coliforms, or Enterococcus and 12-hr rainfall (as well as incremental aggregate rainfall analyses). Once the analysis is completed, the relationships across markers can illustrate patterns of fecal contamination delivery and conveyance. For example, if the HF183 signal is directly and strongly correlated to recent rainfall, it may be that sewage systems are becoming compromised during specific rainfall conditions. This type of information can be useful in prioritizing areas requiring multiple infrastructure fixes. This information would be used to refine the calibration of the model developed as part of this project.

In the face of climate change and sea level rise, it has been important to begin to place tidal influence into the context of stormwater conveyance. The impact of higher tidal elevations in low-lying states such as SC cannot be overstated. This is because the extreme high tides, also known as perigean or king tides, interfere with the conveyance of stormwater to receiving waters. The rising tides have the capability of interfering with stormwater conveyance into receiving waters; adversely impacting sanitary sewer pump station functionality; creating more frequent or longer duration flooding during storm events; inundating water, wastewater, and stormwater infrastructure by daily high tide (which promotes corrosion and pipe damage); and elevating groundwater levels and increasing saltwater intrusion. During periods when the groundwater table is high, the impact of tidal influx paired with saturated soil conditions can exacerbate issues related to exfiltration from the sewage system, causing contamination to reach the groundwater subsurface and be conveyed to receiving waters (Amick and Burgess, 2000). Because low-lying coastal communities depend on gravity to help water move through the stormwater system the absence of gradient with flat topography can cause outfalls to be partially or fully submerged. Exacerbated and repeat high water events can cause the groundwater levels in the coastal communities to be high, further reducing the amount of area available for stormwater infiltration. At the moment, communities are not engineering our coastal plain stormwater or sewage systems to adapt to these conditions.

There are multiple ways to address tidal influence at the outset, including installing check valves, locating force mains in specific locations of interest, removing debris in problem areas, and promoting infiltration in creek and watershed restoration plans. Of initial importance are identifying thresholds at which the performance of the stormwater conveyance system is compromised. Understanding storm scenarios, wind direction, and tidal influence in specific locations can build a local understanding of current and future vulnerabilities. In particular, there will be a need to address the revision of monitoring approaches to best assess the impacts of tidal influence on any particular watershed or subwatershed. Previous studies have sometimes incorporated tide into their sampling methods. But the majority of these studies have been conducted in the western United States or in highly developed watersheds in coastal areas with lower tidal intrusion and greater financial resources to combat coastal flooding. In this circumstance, we are concerned with the risks of increased flooding in low-lying, suburban populations. Therefore, it will be important that we monitor systems in the context of tide in order to gain an accurate representation of tidal inundation and its impact on microbial contaminants conveyed to receiving waters in the Town of Bluffton. If the Town is able to address stormwater conveyance including tidal influence, the Town may have greater success in developing a more-inclusive framework for stormwater management in the face of sea level rise and coastal change.

Key attributes that will benefit a regular monitoring program geared at addressing tidal inundation in the Town of Bluffton are:

- Flow data (e.g. collected using a SonTek-IQ Doppler current meter), automated sampling equipment (such as ISCO samplers), rainfall tracking through the use of tipping rain gauges, anemometers, and other sensors may be useful to employ at specific sites of concern. In tidally influenced areas, however, measurements of flow need to account for tidal influx using other more complicated dispersion models, as negative flows cannot simply be removed from the discharge data (e.g. Stumpf et al. 2010).

- Intra-agency coordination and conversations about engineering and BMP selection in the context of tidal inundation. Partners include federal, state, and local jurisdictions and non-government organizations:
    - United States Geological Survey (USGS)
    - South Carolina Department of Environmental Health and Control (SCDHEC)
    - South Carolina Department of Natural Resources (SCDNR)
    - Beaufort County Public Works/Stormwater Management
    - Beaufort-Jasper Water and Sewer Authority (BJWSA)
- Derivation of all key data for assessing the role of tide in the conveyance of stormwater and sanitary sewer systems, including elevation of all inlets, outfalls, sewer pump stations, and BMPs
- Assessment of adaptive capacity using current scenarios, future scenarios, and in particular with emphasis on concurrent events such as hurricanes where wind-driven forcing and water levels cause combined effects
- Volume reduction and promotion of infiltration, particularly in key subwatershed areas,
- Potential investment in groundwater drawdown approaches in particularly problematic areas (e.g. http://www.wpoa.org/wp-content/uploads/2011/04/WPOA-FloodingStormwater-ManagementPlan.pdf)
- Molecular approaches for assessment of specific sources of fecal contamination (paired with tidal inundation-based monitoring), will assist in prioritizing those locations for immediate action.

5.1.3 Future (new) Water Flow Monitoring Locations

The results from the water quality model could be better calibrated if continuous, non-tidal flow data was available in key areas of the watersheds. This information would be used to refine the calibration of the model.

The Town should set up gages for multiple conditions (baseflow, stormflow, wet seasons, dry seasons). A combination of continuous, long-term (one to two years) and shorter-duration monitoring should be conducted. This would allow the model to be compared to an entire hydrograph and sequential hydrographs rather than a single point (a single flow measurement). After about two years of data collection, the Town should have enough information to create rating curves for these channels, which would allow the Town to know the flow for a given channel depth. Over this 2-year period, it would also be possible to understand seasons with maximum and minimum flow conditions and calibrate this according to rainfall amounts in ensuing years.

1. Establish at least one continuous flow monitoring site in a headwater subwatershed, nearest the outlet but with no or very minimal tidal influence. Potential candidates include upstream from MRR06 (Rose Dhu Creek) or MRR10 (Stoney Creek). At this same station, perform regular bacteria monitoring using a combination of weekly or biweekly (i.e., every other week) grab samples and if possible composite storm sampling.
2. Take flow measurements and bacteria samples (flow and water quality at the same time) at two or three stations farther up in the watersheds and where significant development occurs. Sampling every two weeks is recommended, if possible. Possible candidates include:

a. Duck Pond: add flow monitoring to PBR8B
b. Palmetto Bluff: create a new flow/bacteria monitoring station along the main channel upstream of USGS 02176713 (perhaps near Old Palmetto Bluff Road or Mt. Pelia Rd.)
c. Rose Dhu Creek: add flow monitoring to HH1A, HH2A, and HH8
d. Stoney Creek: add flow monitoring to HL12, HL11, SC7, SC4, BECY1.5
e. It may be of interest to characterize a sewage spill overflow in any of these locations to understand the distribution of fecal contamination and persistence characteristics. Conducting this exercise in the Shingle Creek region of the Nansemond River permitted an ability to characterize the fate and transport of contaminants.

3. Options for flow monitoring equipment:
   a. Sontek iQ units can be anchored into a streambed or deployed temporarily. If temporary, a rating curve should be developed as a QA/QC. The iQ is for 2.5 m or less; the iQ Plus is for up to 5m depths. A diver will be needed for anything deeper than 1.5 m for safety reasons. https://www.sontek.com/sontek-iq-series
   b. For a deep/large reach of a river, especially if there is a good location near a bridge, the Town can consider renting a unit and installing a temporary station in a sideways orientation on a bridge pier. Suggested equipment include:
      i. Teledyne Workhorse
      ii. Sontek Hydrosurveyor
      iii. Sontek Riversurveyor
   c. It may be possible to rent this equipment rather than purchase it. For example, the Geology Department at the College of Charleston has rented an older iQ for a project in Stringer Creek and deployed it for a three-week stretch once or twice per year. It was about $1,000 per month rental fee.

5.2 Strategies and Best Management Practices for Bacteria Reduction

Residential land uses, which are predominant in the May River Headwaters, tend to produce high bacteria loading from a myriad of contributing factors including leaking septic tanks, pet waste pick-up behaviour, as well as turf management and erosion control practices (Wood, 2018). Pollutants in stormwater runoff, such as bacteria, can be managed through both structural and non-structural methods. Structural stormwater BMPs include items such as stormwater ponds, Infiltration BMPs, Filtration BMPs, pervious pavement, bioretention, and stormwater wetlands. Reduction of bacteria varies by BMP and location (site-specific removal efficiencies), and is accomplished through filtration, ultraviolet (UV) or sun exposure, and biological processes. Strategies beyond stormwater BMPs include policies such as septic system inspection, maintenance, and/or conversion to sanitary sewer; street sweeping; pet waste removal education; wildlife management; and prevention of sanitary sewer overflows (discouraging flushing wipes or washing fats oils and grease into sanitary sewer systems; encouraging regular pipe inspections/maintenance; and supporting illicit discharge detection and elimination programs).

On May 29, 2020 Project Team members from McCormick Taylor and Moffatt & Nichol hosted a roundtable discussion with Town of Bluffton staff and Dr. Rachel Noble to strategize approaches to reduce FC populations within the watershed. Dr. Noble emphasized that traditional FIB do not correlate well with the occurrence of pathogens, and they do not identify the source of the contamination. Additionally, many studies – including monitoring efforts by the Town of Bluffton – have documented that FIB can colonize and regrow in biofilms and sediments in the storm drainage system. These constraints of FIB further limit the ability to track the original source of contamination (Burkhart, 2012).

In general, human sewage contamination presents the greatest health risk and is a controllable source; Dr. Noble recommends that this should be the first target of remediation efforts (Nobel and Weisberg, 2005, Steele et al. 2018). This can be accomplished through the use of FIB based routine monitoring. In this particular case, even though fecal coliform are the FIB group of active management, it is prudent to include both fecal coliform and *Enterococcus sp*. FIB as part of the monitoring program. Membrane filtration, IDEXX defined substrate technologies, and multiple-tube fermentation are all appropriate methods to use for this combined assessment. This is because quantification of both targets provides valuable information on inputs of fecal contamination, particularly from sewage systems (see Hart et al. 2020, Gonzalez et al. 2014). In the references cited, routine monitoring was being conducted weekly, but in the case of establishing a new monitoring program, a balance between routine, dry weather sampling and wet weather adaptive sampling must be found. FIB-based monitoring data can be used to rank the sites analyzed, using a concentration-based ranking system. Once this is done, the next step would be to identify sites which ranked highly for both fecal coliform and Enterococcus sp. concentrations. Once FIB-based monitoring data is evaluated, proceed to identification of hot spots for contamination due to either dry or wet-weather or both types of conditions (https://core.ac.uk/download/pdf/84414928.pdf). Based upon available flow information, FIB-based monitoring can be used to then re-rank the hot spots in the context of loading. Once ranking is complete, the top hot spots can be selected for MST-based assessments. These assessments can incorporate human and animal fecal sources in order to build knowledge of the sources of contamination. In some cases, implementation of real-time tracking approaches may be useful in the stormwater and sewage conveyance systems (Virginia Department of Health, Hampton Roads Sanitation District, 2018). It may be valuable in this example provided to attend to the number of SSO events occurring at a particular location or in a particular watershed, because if known wastewater compromises occur, those could be driving patterns observed with the ranking, and those issues are likely to be already being attended to for infrastructure repairs.

When selecting a BMP for bacterial removal, many studies indicate that most BMP data is quite variable and site-specific, which makes it difficult to select a single BMP solution to incorporate into a watershed management plan. Additionally, high removal efficiency does not always guarantee attainment of bacteria standards when inflow concentrations are high (Wood, 2018). For example, if a BMP has 80% removal efficiency, but the inflow is 650 #/100mL, the outflow concentration would be 130 #/100mL – a concentration that is higher than the shellfish water quality standard.

As part of the meeting, Dr. Noble provided an academic review of regional case studies and best practices related to bacteria. The results of this discussion and recommendations will be described in Section 5.4.

5.2.1 Regional Stormwater BMP Design Guidance

Across the nation, and the southeastern region in particular, there is a movement away from stormwater ponds in favor of emphasizing other practices that encourage runoff reduction, which is defined as "the total annual runoff volume reduced through canopy interception, soil infiltration, evaporation, transpiration, rainfall harvesting, engineered infiltration, or extended filtration." Table 42 summarizes the various measures of BMP performance (runoff reduction and removal efficiencies for nutrients, suspended sediments, and bacteria/pathogens) for three design manuals applicable in the Town of Bluffton: *Low Impact Development in Coastal SC: a Planning and Design Guide* (Ellis et al., 2014); the *Southern Lowcountry Stormwater Design Manual* (Center for Watershed Protection and McCormick Taylor, 2020); and the *South Carolina DHEC Storm Water Management BMP Handbook* (SCDHEC, 2005). Still it cannot be denied that stormwater ponds represent stormwater control measures that are capable of nitrogen and solids reductions, and often play important roles in both nitrogen fixation and denitrification, providing useful services (Gold et al. 2019). In the future, there may be modifications to existing wet stormwater ponds such as aerobic mixing or other factors that could promote both bacterial reductions and nitrogen reductions more effectively.

Table 42: Summary of BMP Performance Crediting by Various Authorities

BMP	Runoff Reduction	Total Nitrogen	Total Phosphorus	Total Suspended Solids	Bacteria
Bioretention					
Coastal SC LID Manual	60-100%	65-90%	55-90%	80-90%	55-90%
SoLoCo Manual	60-100%	75-100%	N/A	85-100%	80-100%
SCDHEC	N/A	35-55%	55-70%	50-85%	10-60%
Permeable Pavement					
Coastal SC LID Manual	50-100%	60-80%	60-80%	80%	45-75%
SoLoCo Manual	30-100%	45-100%	N/A	80-100%	30-100%
SCDHEC	N/A	N/A	N/A	N/A	N/A
Infiltration					
Coastal SC LID Manual	100%	55-90%	65-95%	80-95%	65-95%
SoLoCo Manual	100%	100%	N/A	100%	100%
SCDHEC	N/A	35-55%	50-60%	80-90%	90-98%
Green Roof					
Coastal SC LID Manual	100%	45-60%	45-60%	80%	45-60%
SoLoCo Manual	50-100%	50-100%	N/A	50-100%	50-100%
SCDHEC	N/A	N/A	N/A	N/A	N/A
Rainwater Harvesting					
Coastal SC LID Manual	100%	Varies	Varies	Varies	N/A
SoLoCo Manual	100%	100%	100%.	100%	100%
SCDHEC	N/A	N/A	N/A	N/A	N/A

BMP	Runoff Reduction	Total Nitrogen	Total Phosphorus	Total Suspended Solids	Bacteria
Disconnection					
Coastal SC LID Manual	25-75%	25-50%	25-50%	80%	N/A
SoLoCo Manual	40%	40%	N/A	80%	40%
SCDHEC	N/A	N/A	N/A	N/A	N/A
Grass Channel					
Coastal SC LID Manual	10-20%	20-35%	40-45%	40%	N/A
SoLoCo Manual	10-20%	25-35%	N/A	50%	30%
SCDHEC	N/A	N/A	N/A	N/A	N/A
Dry Swale/Bioswale					
Coastal SC LID Manual	60%	20-35%	40-45%	40%	N/A
SoLoCo Manual	10-20%	25-35%	N/A	50%	30%
SCDHEC	N/A	40-60%	35-50%	70-80%	10-60%
Filtering Systems					
Coastal SC LID Manual	0	45%	65%	90%	80%
SoLoCo Manual	0	30%	N/A	80%	80%
SCDHEC	N/A	N/A	N/A	N/A	N/A
Dry Detention					
Coastal SC LID Manual	0	N/A	N/A	N/A	N/A
SoLoCo Manual	0	10%	N/A	60%	60%
SCDHEC	N/A	19-29%	14-25%	45-68%	20-50%
Wet Detention Pond					
Coastal SC LID Manual	0	40%	75%	85%	70%
SoLoCo Manual	0	30%	N/A	80%	60%
SCDHEC	N/A	30-45%	50-70%	65-80%	45-75%
Stormwater Wetland					
Coastal SC LID Manual	0	30%	50%	80%	70%
SoLoCo Manual	0	25%	N/A	80%	60%
SCDHEC	N/A	28-39%	42-53%	66-78%	58-78%

5.2.2 State of Knowledge of Bacteria Reduction Strategies and BMPs

In order to make recommendations for best management practices (BMPs) for the May River Headwaters, the Team researched current information from academia and the public utilities sector to understand the current state of the knowledge related to reducing FIB. Recognizing that human sewage contamination presents the greatest health risk and is a controllable source, the first recommendation is to identify sources of human sewage and then fix underperforming septic systems and/or sanitary sewer conveyance systems (see Section 5.1). Any recommendations for structural stormwater BMPs will not have an impact if the actual bacteria source is from failing septic and sewer infrastructure. Failing septic and sewer systems can be the result of age, maintenance issues (clogs), or even tidal influence. Rising tides have the capability to interfere with both stormwater and sewer infrastructure, by impeding flow and promoting corrosion. An additional complicating factor to address bacteria, as the Town has documented with its monitoring program, is that FIB can colonize and regrow in biofilms and sediments in the storm drainage system. Therefore, even if a BMP is successful at reducing the concentration of FIB in the effluent, there is still a problem of FIB persisting in hospitable environments.

The research also indicated that BMP efficiency is variable and dependent on the design, maintenance, and other factors. For example, in some cases a net export of microbes can result due to improper maintenance, regrowth of microbes in the BMP, resuspension during storm events, or direct wildlife deposits (Characklis et al., 2009). Information regarding removal rates of FIB in the International BMP Database (Clary et al., 2010) are variable and dependent on the following, 1) season in which the FIB were quantified; 2) stormwater volume and flows; and 3) the type of FIB being measured. For example, lower values of removal efficiency have been reported for *Enterococcus* bacteria because this genus is saprophytic (plant-loving) and can persist and grow in vegetated systems. This trait is of importance as *Enterococcus* is a subset of FC bacteria. Several systems reported the best removal efficiencies in systems with low turbidity as sunlight penetration enhances UV degradation of bacteria, and this process is reduced in high turbidity conditions (Noble et al., 2002). Dr. Noble advised the Project Team and Town that removal values in coastal SC will most likely be lower than those included in the International BMP Database, which has many studies based on the West Coast. This is primarily due to the following, 1) SC temperature is higher during most seasons than in west coast environments; 2) SC water sources tend to be blackwater and tannic water, which reduces light penetration; and 3) persistent forms of FC are known to grow in the sediments of systems in SC.

Wet Ponds, whether as stormwater BMPs or as community amenities, have become a dominant feature in the landscape in the May River Headwaters (Table 25). GIS shapefiles of ponds provided by the Town of Bluffton were compared to historic aerial images in 2002 and 2018. Although ponds are a reliable flood prevention practice, their ability to treat bacteria is variable. Weinstein et al. (2008) demonstrated that bacterial levels in ponds were positively correlated with the size of the pond's drainage area, pond surface area, concentrations of total organic carbon, and percent clay particles. Local design guidance manuals (SCDHEC, 2005 and Ellis et al., 2014) estimate bacteria removal efficiencies in wet ponds to be 45-75%. A more conservative range might be 50 to 60%. The higher removal efficiency is likely to be appropriate for fall and winter months, and the lower removal efficiency values are likely to be more appropriate for the spring and summer months, where organic matter and primary productivity values are expected to be greater.

There are very few fully quantitative evaluations of wet pond removal efficiency of FIB (Appendix B. Noble, 2020). Many studies evaluated for this report state that FIB removal efficiencies are not well established for wet ponds/retention ponds/retention basins. The Town of Bluffton does have water quality monitoring and statistical analysis of the results that evaluate the effectiveness of a 1.25 acre wet pond (with a drainage area of 300 acres) that was constructed as a recommended project in the 2011 Action Plan (New Riverside Pond, or Area A in Figure 16 of this report). The New Riverside Pond (NRP) was completed with 319 grant funding in 2013. The Town monitored FC concentrations at locations immediately prior to treatment (influent site NRP-IN-N), after treatment (effluent site NRP-OUT), and at locations approximately 600 ft (BECY1.5) and 1,320 ft (PBR9, outfall to May River). In 2015, Dr. Warren from the University of South Carolina provided a statistical review of the Town's NRP FC data. The results of this analysis (Warren, 2015) showed that there was a statistically significant reduction in bacteria concentrations between the pond influent (NRP-IN-N) and pond effluent (NRP-OUT). Additionally, there was a statistically significant reduction in FC concentrations at BECY1.5 for observations before and after the pond was constructed. However, at the outfall to the May River (PBR9), the was no statistically significant reduction in FC concentrations before and after the pond was constructed. In other words, even though a large stormwater treatment BMP was installed and effectively removed FC, there was not a benefit to the May River because the bacteria levels still increased downstream of the pond. As a result, the Town decided to utilize Microbial Source Tracking (MST) to evaluate what is the source of FC and inform new actions that could be taken to improve the efficacy of the BMP. As a result of MST, the Town identified 5 failing septic systems in the Headwaters of the May River (Jones and Lewis, 2019).

One study (Hathaway, 2008; Hathaway et al., 2009) conducted in Charlotte, NC evaluated the performance of nine stormwater BMPs, including one wet pond, two stormwater wetlands, two dry detention basins, one bioretention area, and three proprietary devices. The data from this study was conflicted and sometimes confusing. The authors reported a greater than 50% removal efficiency for fecal coliform and *E. coli* in the wet pond, wetlands, bioretention area, and the proprietary device. However, only the wetlands and the bioretention area had significantly different influent and effluent concentrations. The authors called attention to the nature of temperature-warm, nutrient-rich, stagnant BMPs systems that appear to serve as a reservoir of FIB and at times may also preferentially grow the fecal indicator bacteria (Van Donsel et al., 1967).

In Australia, there is a reasonable similarity between their waste stabilization ponds and retention ponds in SC. A recent study (Sheludchenko et al., 2016) studied FIB removal rates in four waste stabilization ponds. One of the ponds had baffles to promote surface area in the ponds in areas where space is a constraining factor. The waste stabilization pond with baffles showed a reduction in both pathogens and FIB. When FIB studies were conducted with more replicates at a later time, the team found a ten-fold reduction in the total number of E. coli in the system, indicating a removal efficiency of roughly 90% of the system.

The International Stormwater BMP database contains approximately 600 pairs of influent and effluent data for fecal coliforms and *E. coli*. across multiple states. Clary et al. (2008) analyzed the fecal coliform and *E. coli* data and showed that swales and detention basins did not appear to effectively reduce FIB in effluent samples. Datasets for wetlands and manufactured devices were not of adequate size to draw meaningful conclusions, but sometimes these systems showed bacterial growth. The authors concluded that the ability of BMPs to reduce FIB varies widely across BMPs. No single BMP appears to consistently reduce FIB concentrations. Among the BMPs, retention pond and media filters appeared to show some positive trends, but these were not across the board. Chandrasena et al. (2016) studied the removal of *E. coli* and *Campylobacter spp*. from urban stormwater by field-scale biofilters.

Additionally, high removal efficiency does not always guarantee attainment of bacteria standards when inflow concentrations are high (Wood, 2018). As a result, across the southeastern region and nation, there is a movement away from stormwater ponds in favor of emphasizing other practices that encourage runoff reduction, which is defined as "the total annual runoff volume reduced through canopy interception, soil infiltration, evaporation, transpiration, rainfall harvesting, engineered infiltration, or extended filtration."

5.2.3 Future Strategies to Consider

Based on the understanding of the state of knowledge and approaches used by watershed managers to minimize and mitigate the effects of development on water quality, the Project Team held discussions with the Town of Bluffton to develop the following list of strategies for addressing FC in the May River Headwaters. In general, the strategies involve Four Ps: Partnerships, Policies, Programs, and Projects. Overall, the goal will be to follow Better Site Design principles to conserve natural areas including tree canopy, reduce impervious cover, and manage designated stormwater reduction volumes by infiltration and/or filtration techniques as first priority, or other approved volume reduction techniques as second priority. These strategies are in agreement with local research (Holland et al., 2004; Sanger et al., 2008; Sanger and Blair et al., 2015; Sanger and Tweel et al., 2015; Montie, 2019) pertaining to the negative impacts of impervious surfaces in southeastern estuarine environments and are supported with design guidance (such as *Low Impact Development in Coastal South Carolina: A Planning and Design Guide*) and in local ordinances. The Town of Bluffton is currently in the process of adopting a new regional stormwater design manual and ordinance with Beaufort County, Jasper County, the City of Beaufort, City of Hardeeville, and Towns of Port Royal and Yemassee.

Partner organizations to protect and improve water quality in the May River watershed include:

1. Beaufort County – Public Works, Stormwater, Parks & Recreation, Rural & Critical Lands
2. Beaufort-Jasper Water and Sewer Authority (BJWSA)
3. Clemson Extension/Lowcountry Stormwater Partners
4. South Carolina Department of Natural Resources (SCDNR)
5. South Carolina Department of Health and Environmental Control (SCDHEC)
6. United States Environmental Protection Agency (USEPA)
7. National Oceanic and Atmospheric Administration (NOAA)
8. United States Geological Service (USGS)
9. University of South Carolina Beaufort (USC-B)
10. University of South Carolina
11. Clemson University
12. Public Schools/Board of Education
13. Non-governmental organizations, e.g. Lowcountry Institute, Port Royal Sound Foundation, Open Land Trust
14. Private Commercial Properties
    a. Residential HOAs/Communities
    b. Religious Institutions
    c. Apartment Complexes
    d. Private Education Campuses
    e. Shopping Centers
    f. Others

Policies to protect and improve water quality in the May River watershed include:

1. Adopt proposed regional Southern Lowcountry Post Construction Stormwater Ordinance and Design Manual.
    a. The Town should incorporate volume reduction BMPs (those that encourage infiltration) within existing and future CIP projects to the maximum extent practical, especially for project locations with well-drained soils (HSG A or B)

2. Eliminate clear cutting approach within developed areas.
3. Increase buffer areas and requirements.
4. Increase conservation and open space requirements and require recorded conservation easements.
5. Reduce planned density/re-zone.
6. Increase tree protection/conservation areas and requirements
    a. Increase tree protection area from drip line to an additional 25' from drip line.
7. Offer incentives to renegotiate existing land development agreements to reduce density and meet current environmental objectives.
8. Develop strategies to effectively execute public/private partnerships.

Programs to protect and improve water quality in the May River watershed include:

1. Continue to support the Municipal Separate Storm Sewer System (MS4) program in the Town and County as they work to achieve the six (6) Minimum Control Measures, including:
    a. Public education and outreach
    b. Public participation/involvement
    c. Illicit discharge detection and elimination
    d. Construction site runoff control
    e. Post-construction site runoff control
    f. Pollution prevention/good housekeeping
2. Neighborhood Assistance Program
    a. Septic System Assistance Program to assist Town residents with septic system maintenance to ensure proper functioning until sanitary sewer connections are available.
    b. Septic to Sewer Conversion Program to assist Town residents with offsetting the potential costs to abandon existing septic systems and connect to available public sanitary sewer.
3. Establish an Impervious Area Restoration/Retrofit Program in areas where development pre-dated stormwater management requirements or failed to meet on-site retention of the 95th percentile storm. The purpose of this Program is to target large impervious areas to be retrofitted to meet 95th percentile storm retention of impervious surfaces with infiltration/filtration BMP to the maximum extent possible.
4. Water Quality Monitoring Program modifications include
    a. Developing in-house microbial source tracking
    b. Recommendations for future bacteria monitoring locations
    c. Recommendations for future water flow monitoring locations

Projects to protect and improve water quality in the May River watershed include a variety of stormwater BMP structures. Consideration of site-specific factors, such as in-situ soils, site stability, seasonal high-water table, cost, utilities, and even aesthetics will factor into selection of appropriate practices for a given site. For example, practices that focus on infiltration will not be feasible in areas with high groundwater levels, poorly drained soils, steep slopes, and utility conflicts. Additionally, these structures will require dedicated maintenance to ensure a long and effective service life. Information related to maintenance requirements can be found for individual BMPs in Chapter 4 of the *Southern Lowcountry Stormwater Design Manual* along with checklists in Appendix F and maintenance agreement template in Appendix O. Recommended types of projects include:

1. Impervious Surface Rehabilitation/Retrofit: As development increases in response to population growth, there are measurable anthropogenic impacts on natural systems and tidal creeks in particular (Holland et al., 2004; Sanger et al., 2008; Sanger and Blair et al., 2015; Sanger and Tweel et al., 2015). Regional research has demonstrated that when the impervious cover exceeded 10-20% in a watershed, measurable physical and chemical changes were observed, such as altered hydrography, increased salinity variance, altered sediment characteristics, increased chemical contaminants, and increased fecal coliform loadings. Furthermore, measurable impacts were observed in living resources and ecological processes when impervious cover exceeded 20–30%. Health risks and flooding vulnerability of a headwater region becomes a concern when impervious cover exceeds 10-30%.

   Converting impervious surfaces to pervious or removing excess impervious surface is recommended to the maximum extent practicable in accordance with the new *Southern Lowcountry Post Construction Stormwater Ordinance and Design Manual.* If pavement cannot be removed or converted, street sweeping is a recommended strategy for removing sediment from the surfaces to prevent pollutants and bacteria (which adsorb to the sediment particles) from entering stormwater ponds and conveyance systems.

   Potential Impervious Surface Rehabilitation/Retrofit project types include:

   a. Permeable Pavement allows for stormwater volume reduction through infiltration, and is ideal for parking areas, shoulders, and travel lanes. Stormwater passes through various pervious layers and is stored in a gravel reservoir prior to infiltration. In areas of poor soils, an underdrain can be installed to provide detention of stormwater with a managed discharge into a receiving storm drain. Permeable pavements can be constructed from concrete, asphalt, gravels, and various pavers. In some cases, a pervious trench can be installed along a gutter pan or road edge to capture stormwater flow. Varying in width up to four feet wide, these infiltration trench systems results in reduced costs as only a portion of the road needs to be reconstructed. Opportunities for permeable pavement include
      i. Pervious driveways: explore opportunities to retrofit existing residential driveways by removing the paved surfaces and replacing with gravel, pavers, grass grids, etc.
      ii. Pervious parking lanes/gutters: convert a portion of low-traffic lanes or on-street parking to pervious material.
      iii. Note there are several publicly owned roadways in the May River Headwaters, including Bluffton Parkway, Buckwalter Parkway, Grande Oak Drive, Heartstone Circle, Morningside Drive, and Lake Point Drive. As these roadways are repaired and maintained, the Town should coordinate with Beaufort County to consider incorporating projects such as bioswales, infiltration trenches, and permeable pavement strips for future roadway capital improvement projects.
   b. Pavement reduction: look for opportunities to shrink parking lots by providing compact car spaces, minimizing stall dimensions, and providing shared parking. Review existing parking ratios to determine if a lower ratio would be warranted or feasible.
   c. Incentives to improve Planned Unit Development (PUD) agreements: reduce the amount of developed area and preserve natural areas to the maximum extent possible, increase buffer areas; reduce density; design residential streets for the minimum required pavement width needed to support travel lanes, on-street parking, and emergency vehicles; reduce the total

length of residential streets by utilizing alternative layouts to maximize number of homes per unit length; and minimize cul-de-sacs.

2. On-site Volume Reduction: This technique requires stormwater to be managed on-site, either during development or as a retrofit, rather than conveyed to a downstream BMP or receiving water. This is achieved through infiltration and evapotranspiration to mimic the pre-development hydrology of the site. The new *Southern Lowcountry Post Construction Stormwater Ordinance and Design Manual* (Center for Watershed Protection and McCormick Taylor, 2020) require development or redevelopment in watersheds designated for shellfish harvesting, or under water quality impairments, to retain the 95th percentile storm (1.95") on-site through use of infiltration or filtration practices to the maximum extent practicable (MEP).

   In areas where development pre-dated stormwater management requirements or failed to meet on-site retention of the 95th percentile storm, it is recommended the Town of Bluffton institute an Impervious Area Restoration/Retrofit Program (as described above) in which large impervious areas are targeted to be retrofitted to meet 95th percentile storm retention of impervious surfaces with infiltration/filtration BMP to the maximum extent possible. Most BMP and engineering construction practices will benefit from a vision to include BMP modification, dredging and maintenance over a five-year performance period. The maintenance of the BMP should include incorporation of expected (e.g. dredging of sediment during high rain periods and unexpected costs (i.e. saltwater inundation of a vegetated wet pond during a hurricane).

   Potential On-site Volume Reduction project types include the following:

   a. Bioretention/Rain Gardens: these are practices that capture and store stormwater runoff in shallow vegetated basins containing engineered soil media. They are designed to infiltrate runoff through an engineered media of sand, soil, and organic matter that is 18" deep; the water can then be returned to a conveyance system via an underdrain if surrounding soils do not support infiltration. These are easily incorporated into new development and retrofit projects. They are a good choice for small, highly paved drainage areas such as parking lots or alongside roadways. Additionally, the footprint of these practices can be adjusted to accommodate existing utilities and other site constraints.
   b. Bioswales/Dry swales: a type of open channel system designed to function like shallow, linear bioretention units. They can be covered with elaborate landscaping, simple turf or other surface material. Bioswales use identical soil filter media as bioretention and can be equipped with an underdrain or allow runoff to infiltrate into surrounding soils. Check dams should be constructed to encourage ponding.
   c. Filtering Systems/Trench: These practices temporarily store stormwater runoff and pass it through a filter bed of sand media. They are useful in small drainage areas, especially those with high impervious areas or as retrofits to existing developments. The *Southern Lowcountry Design Manual* recognizes several variations in types of filters: non-structural sand filters, surface sand filters, underground sand filter, three-chamber underground sand filter, and perimeter sand filter. These practices do not receive credit for reducing stormwater volume; however, they can be highly effective at removing bacteria from stormwater runoff.

d. Cisterns/Rain Barrels: Rainwater harvesting is a technique that captures and stores rainfall (in tanks above or below ground) in order to release it for future use. Advantages of this strategy include reducing the rate and volume of stormwater runoff and providing water for non-potable uses such as irrigation and toilet flushing. In order to maintain capacity, the stored water must be used on a regular basis. Ideal in residential areas as a grassroot effort within a community, local jurisdictions (Town of Bluffton, Beaufort County) and other organizations (e.g. Lowcountry Stormwater Partners) can support distribution of rain barrels to neighborhoods. Harvested rainwater can be used for non-potable water uses and on-site stormwater disposal/infiltration. Non-potable uses include landscape irrigation, exterior washing, flushing of toilets and urinals, fire suppression (sprinkler systems), evaporative coolers, and replenishment of water features/fountains. Additionally, rainwater harvesting can be combined with a secondary (down-gradient) stormwater practice to enhance stormwater retention and/or provide treatment of overflow from the rainwater harvesting system. This could include disconnection to a pervious or conservation area (disconnection) or overflow to practices such as bioretention, infiltration, or grass channels/dry swales (Ellis et al., 2014).
    i. A related practice is utilizing stormwater ponds for irrigation purposes. The pond acts as the cistern, storing water until it is utilized for irrigation. Anecdotally, this practice has been used by golf course communities to irrigate turf, but it can also be applied in other areas such as HOA common space such as in the Town's Pine Ridge project. This practice fulfills the objective to retain stormwater volume on-site, but the amount of bacteria reduction associated with it has not been documented.

e. Green Roofs: These practices capture and store rainfall in an engineered growing media installed over a waterproof membrane on a building or other structure. They have moderate to high water quality improvement because they can reduce runoff volume and pollutant loads. They provide additional benefits such as energy savings and potential for amenity space for users. There are modular green roof units available on the market (for example, Green Roof Outfitters) that make retrofits of existing buildings easier.

f. Infiltration Facilities: These storage practices are a type of underground detention vault or tank with an open bottom to allow for infiltration. The units can be made from a variety of materials (plastic, concrete), shapes (domed, square) and sizes (from about 30 inches to 15 feet in depth), allowing them to be configured to adapt to many site conditions. With adequate soil types (minimum infiltration rate of 0.5 in/hr), subsurface infiltration results in stormwater volume reduction. Paired with underdrain or a low flow orifice, these systems provide stormwater detention and peak discharge reduction.
    i. An example project in the City of St. Paul diverted water from an existing stormwater pipe (draining 63 acres of land) into an infiltration basin constructed under an existing golf course fairway: https://www.capitolregionwd.org/projects/como-golf-course/ Note that there are three golf course communities in the May River Headwaters, including Hampton Hall (SUB-RD-08, 09, 10, 11, 17), Old Carolina (SUB-RD-06), and Pinecrest (SUB-RD-06, 12, 13).

Table 43: Volume Reduction Site Selection Criteria

Criteria	Description
Property Ownership	Public>HOA>Religious>Commercial>Private Property
Soils	• HSG A/B soils preferred over C/D; however, it is still possible to achieve infiltration in soils with a permeability as low as 0.5 in/hr. • In poorly drained soils, utilize an underdrain. The *Southern Lowcountry Stormwater Design Manual* gives several BMPs runoff reduction and bacteria removal credits even if an underdrain is used. For example, bioretention with an underdrain has 60% runoff reduction and 80% bacteria removal.
Groundwater Table	• Most BMPs require a minimum depth of 6 inches below the bottom of practice and the seasonal high water table. Maximizing the distance between the groundwater table and the bottom of the practice should allow for more storage and infiltration of stormwater.
Impervious Area	• Most BMPs perform best (are less prone to clogging) if most of the contributing drainage area is impervious. • Potential project sites will be prioritized based on the impervious area treated (projects with more impervious area or located in a subcatchment with high impervious area % should be considered first)
Available space	• A detailed site survey should take into account utilities and other natural resources (such as trees) in order to avoid impacts. This may change the conceptual layout of the projects. • Existing stormwater ponds reduce available space for structural BMP retrofit projects. These may be opportunities for irrigation reuse or other modifications to make ponds bacteria neutral.

3. Modifications to Make Ponds Bacteria Neutral (Pond Retrofit)
    a. Sedimentation to Minimize Dissolved Organic Material: There is a difference between bacterial growth and bacterial persistence. The bacteria cannot grow in the system without a growth substrate, so maximizing the removal of dissolved organics by physical removal, or by additions of nonreactive material (clay) for flocculation is a potential strategy to reduce bacterial growth. Additionally, bacteria that attached to sediment particles can be settled out using the same method. Systems in which non-reactive material or flocculation is to be

promoted need to consider the additional services of the BMP, so as to ensure that management of bacterial concentrations does not come at the cost of expected nitrogen or solids reductions (e.g. Gold et al. 2019).

b. Low Flow Orifice Manipulation: Discharge from existing ponds can be adjusted to retain more water. In some instances, the discharge structure can be retrofitted with an additional orifice that would allow for the lowering of the permanent pool elevation prior to a rain event. This would allow the capture of additional runoff, and residency time to allow for UV disinfection, settlement of solids, and evaporation prior to the engagement of the standard low flow orifice or weir. This would also allow the peak discharge to be lowered reducing the freshwater volume contributed into the downstream tributaries. This would only be suitable in instances where the outfall elevation is lower than the permanent pool, or where groundwater levels are not influencing pool elevation. Consideration should be given to hydrograph peaks and inadvertently overlapping peak discharges that may result in downstream flooding.

c. Pond Lining for Groundwater Separation: Stormwater ponds may interact with the groundwater table. Interaction with ground water may be the original design intent, or a result of over excavation of the ponds to a depth greater than displayed in the permit drawings. As a result, the groundwater fills the ponds, which may cause a constant discharge of freshwater out of the pond and into the receiving conveyance system. This creates two problems: a pond that does not provide adequate treatment (hydraulic residence time is too short to allow bacteria to be eliminated by sedimentation or UV treatment) and additional freshwater that encourages bacterial growth downstream of the BMP. There are several approaches to segregate groundwater from wet ponds and in some instances a combination of several may be needed. If a pond was found to be over excavated, it could be backfilled to an elevation above the ground water interface. A liner can be installed, though this would require draining of the pond. Pond liners are usually made with a "concrete cloth" that hardens on hydration to form a waterproof layer, a rubber or plastic type membrane, or clay material. They tend to be expensive, and there is a chance that if the pond is already being fed by a groundwater source that it would be difficult to get the material to set properly. Paired with a pond liner, a curtain drain can be constructed around the pond perimeter to capture and redirect groundwater to the outfall.

d. UV Light or Ozonation Treatment: Both methods are expensive but may be effective options to reduce bacteria concentrations. Several examples of these systems' (e.g. https://www.waterworld.com/home/article/16190542/uv-disinfection-facility-treats-stormwater-runoff), https://www.smgov.net/uploadedFiles/Departments/OSE/Categories/Urban_Runoff/UR_SMURRF_Info_Sheets.pdf) observed results exhibit significant reductions of bacteria. However, this approach is probably not feasible given the flows observed in the May River Headwaters Watershed. An ideal situation for these types of systems involves small dry weather flows to very high recreational use areas (such as public beaches) to make the costs worthwhile.

Note that before a stormwater pond retrofit can occur, more data is required to evaluate, rank, and prioritize projects. Stormwater ponds are often designed to meet a minimum requirement that meets water quality and quantity storage and management guidelines. This storage volume, either a wet pool or temporary detention volume above the permanent wet pool is based on the contributing drainage area and difference between pre-developed and developed land use. However, there may be opportunities to increase the permanent pool or temporary storage volumes to provide stormwater volume reduction or enhanced water quality management through retrofitting existing ponds. Retrofitting can take the form of several approaches. By calculating the water quality volume required based on enhanced design guidelines, or utilizing a wooded, good condition, pre-developed land use, a water quality storage volume can be determined that exceeds the pond's original design volumes. Trough grading or modification of the discharge control structure additional storage volume can be added to a stormwater pond. Additional water quality storage from the permanent wet pool can be obtained by drawing down the permanent wet pool prior to a rain event. This can be achieved through two methods: an automated low flow orifice that opens prior to the storm event, draining down the permanent pool to allow more runoff to be capture before the original low flow orifice engages, alternatively, the pond water can be used for irrigation and withdrawn via pump. Stormwater withdrawn for irrigation purposes will infiltrate into the ground resulting in true volume reduction. The other methods may reduce the overall peak discharge, but primary benefit is a result of increased retention times for UV disinfection, sedimentation, and evapotranspiration.

Table 44: Pond Retrofit Site Selection Criteria

Criteria	Description
Property Ownership	Public>HOA>Religious>Commercial>Private Property
Are As-Builts Available?	• Yes – would allow for more efficient review for retrofit potential • No – survey of pond would be needed to evaluate for retrofit potential o Area could be flown by drone, with key points picked up with traditional survey.
What is the original pond design?	• Water surface elevation (Permanent pool, design storm events, 100-year) • Pool volume (Permanent, design storms) • Water quality volume (based on requirements when pond was permitted)
Is depth of pond known?	• Is a bathymetric survey needed?
What would the water quality volume be if based on the *Southern Lowcountry (SoLoCo) Stormwater Design Manual* Guidelines?	• Can this difference be treated within existing pond?
Can pond be enlarged through grading or weir modification to store this increase in volume?	• Based on surface area of pond, modification of side slopes or open space area may accommodate the desired additional water quality volume.

<table>
<tr><td></td><td>Would raising or manipulating the low flow orifice to increase water quality storage volume result in acceptable change to pond dynamics (water surface elevation, inundation elevations during rain events)</td></tr>
<tr><td>What is the ground water elevation in relationship to bottom of pond?</td><td>If ground water elevation is equivalent or higher then pond bottom, limits ability to retrofit pond. Investigate feasibility of installing liner to separate pond. Typically cost prohibitive or difficult and very impactive construction methodology to install.
If there is separation between ground water and pond bottom, potential to efficiently retrofit pond through techniques discussed below.</td></tr>
<tr><td>Permanent pool elevation versus elevation of downstream channel</td><td>Advance draw down would create additional storage to capture and treat more runoff from a rain event before the low flow orifice is engaged.
Is there adequate elevation change to draw down permanent pool by gravity before rain event through automated low flow orifice valve?
If there is not enough elevation change, would installing a pump to draw down the permanent pool be feasible?
If ground water is intercepted by pond, this method may not produce noticeable affects to water surface elevation due to the ground water make up.</td></tr>
<tr><td>Evaluate potential to install irrigation withdraw from pond:</td><td>Does the pond currently have irrigation withdraw?
No – proceed to concept design
Yes – investigate expanding system or modifying frequency of irrigation to increase withdraw amount.
What are the Infiltration rates of land to be irrigated? How much water can be applied in a reasonable rate that would infiltrate and not create a detriment to vegetation or land use.
Is there an existing irrigation system (pipes and spray heads) that can be utilized, or would new system be required?
Can private property within neighborhood be included in the pond-based irrigation system? Or would it be limited to HOA common areas.
Can the irrigation be extended to public ROW along roads outside of the neighborhood?</td></tr>
</table>

	• If ground water is intercepted by pond, this method may not produce noticeable affects to water surface elevation due to the ground water make up.
Other Approaches:	• Can the area around the pond be planted to increase evapotranspiration? • Can tree canopy be introduced in open space areas • Increase pond riparian buffer to filter overland runoff into ponds and uptake additional nutrients, etc. • Will improved post-construction inspections and maintenance fix problem? (Partnerships with Carolina Clear and Lowcountry Stormwater Partners can provide support and tools)

4. Proprietary Products to eliminate bacteria. There are many manufactured stormwater treatment practices that utilize settling, filtration, absorptive/adsorptive materials, vegetative components, and/or other technology to manage the impacts of stormwater runoff. The actual performance varies based on the manufacturer's design.
    a. Biosoil Filter Media: various proprietary blends, including amendments such as biochar (Afrooz and Boehm, 2016), can be added to the soil media used for bioretention and other Low Impact Development (LID) practices to help enhance bacteria removal.
    b. Urban Tree Filter Box: These practices function like a smaller bioretention unit installed in the sidewalk zone near the street where urban trees are normally planted. The soil volume for the tree pit is increased and used to capture and treat stormwater. Treatment is increased by using a series of connected tree planting areas sequentially in a row. Sometimes the filter media can be covered with pervious pavers or cantilevered sidewalks.
    c. Filter tubes with bacteria inhibitors such as Bactoloxx filter media: a product marketed by Filtrexx that is used in their EnviroSoxx product to reduce up to 99% of coliform bacteria (including *E. coli* and fecal coliforms) loads in stormwater runoff, particularly around sensitive watersheds and receiving waters. Rather than incorporating the media into the actual BMP, the filter tubes can be placed at inlets or within channels to filter water as it passes through the conveyance system.

5. Nature-Based Solutions
    a. Tree Planting/Reforestation/Urban Tree Canopy: This practice is recommended in the new *Southern Lowcountry Stormwater Design Manual*. Runoff reductions are based on the size of the tree. Tree plantings and preservation have high community acceptance, relatively low maintenance requirements, and are easily incorporated with other practices. Tree planting and preservation provides stormwater interception, beauty, and shade while simultaneously increasing community aesthetics and property values. Tree canopies intercept rainfall before it becomes runoff and can be especially helpful in areas where the canopy covers impervious

surfaces (e.g. street trees). Trees can reduce stormwater runoff volumes and improve water quality through the processes of evapotranspiration and nutrient uptake. Additionally, as the trees' roots grow, they improve the infiltration capacity of the soils where they are planted.

b. Land Purchase/Conservation Areas: Conservation of natural areas is one of the principles of Better Site Design and will contribute to a watershed approach to stormwater management. The *Southern Lowcountry Stormwater Design Manual* provides four scenarios where conservation can qualify for a stormwater retention credit (removal of the area from the site for purposes of calculating the stormwater retention volume, SWRv). These include the following:

    i. Natural conservation area: subtract 100% of the protected area from SWRv calculation if a portion of the post-developed area is left in its natural condition and protected in perpetuity by a conservation easement.

    ii. Reforestation/revegetation: subtract 50% of an area that is reforested/revegetated and placed under a conservation easement from the SWRv calculation.

    iii. Soil restoration: subtract 50% of an area that is restored and placed under a conservation easement from the SWRv calculation

    iv. Reforestation/revegetation and soil restoration: subtract 100% of the acres of development with restored soils and revegetated area from the total site area when calculating the SWRv.

c. Floodplain Restoration: Natural channels and ditches (previous natural channels that have been heavily modified by man) can input pollutant loads into the May River through erosion of fresh and reservoir FIB within the conveyance channel. In this case, the FIB population has become decoupled from any respective pathogens, but the loading remains and is a concern. Due to erosion or continued dredging of these channels, runoff no longer has the ability to access floodplains and adjoining wetlands. Restoration and reconnection of the stream to the floodplain prior to reforestation will promote nutrient and sediment attenuation, reduce flow and scour, and encourage natural hydrological functions in the stream corridor (Ellis et al., 2014). Correcting an incised channel has the potential to increase infiltration, UV penetration (depending on location), and slow down the flow of water to allow sediments/FC to settle out. Several options exist to retrofit these channels which include stabilization of eroded areas through the use of natural stabilization methodologies, re-establishment of flood plains to slow down and encourage evapotranspiration of rain events or the construction of regenerative stormwater structures within ditches and ephemeral channels. In order to make recommendations for restoration of natural channels or ditches, more information is needed at this time, as summarized in Table 45.

Table 45: Ditch/Channel Retrofit Site Selection Criteria

Criteria	Description
Property Ownership	Public>HOA>Religious>Commercial>Private Property
What data is available? (allows for cost efficient concept development)	• GIS (contours, utilities, drainage infrastructure) • As builts or stormwater management plans within the watershed • Previous studies
Site Access	• Adjoining areas heavily forested would affect access • Proximity to public road or right of way • Utility/infrastructure constraints
Adjacent environmental features (such as wetlands)	• Potential to limit site access, create additional permitting complications and potential for mitigation based on impacts (permanent or temporary)
Stream Channel Geometry	• Cross section dimensions, • channel length, • inverts
Current Condition	• Is there erosion/scouring • What kind of substrate: sediment, vegetation (what type: herbaceous, woody, sparse), other (e.g. concrete)? • Is there evidence of tidal influence (flow in both directions or only one?) • Sediment build up within channel
Identify the cause or sources of pollution or subject of concern	• Hot spot • Development • Lack of watershed stormwater management
Natural resources inventory	• Are there RTEs? • Historical impacts?
Ground water separation	• If separation is present, possible for regenerative stormwater style bmp within channel
Mitigation bank credits	• Is there the potential for project to gain wetland or stream mitigation bank credits, allows for funding source?
Condition of outfalls	• Can be significant source of sediment transport
Complete Rapid Stream Assessment by identifying	• Fish blockages • Bank erosion • Outfalls

	• Channel alterations • Flood or infrastructure concerns • Potential for habitat enhancement

Site Prioritization Parameters	• Constructability
	  o Access
	  o Forest / Tree Cover
	  o Utilities (Visible) — Constraints
	  o Proximity to State/County Road
	  o Bank Erodibility Potential
	• Watershed Characteristics
	  o Stream Length (LF) – longer stream lengths are typically more cost effective and result in increased nutrient/sediment reductions
	  o Drainage area – smaller drainage areas (< 1 square mile) have higher probability for success.
	  o Stream order – 1st order systems are optimal
	  o % Impervious – optimal is < 10% impervious, however many urban systems fall in suboptimal category of 10-29%
	  o Biologic Uplift – look for streams that have potential for biologic uplift or habitat improvements in addition to stabilization
	• Other
	  o Bank Erodibility Potential – Are there active headcuts or high potential for new headcut migration? High channel incision?
	  o Stream Bank Erosion Potential Percentage – Higher percentage of bank erosion provides greatest pollutant reductions. Need to look at both banks.
	  o Sediment Storage / Nutrient Treatment Potential – includes treatment of upstream sources, floodplain storage and/or nutrient treatment potential
	  o Potential to incorporate other BMP strategies – strategies could include reforestation, wetland creation, trash removal, outfall restoration, upland BMPs
	  o Flooding/Drainage history: impact on conveyance efficiency and increased flood risk

5.3 Evaluation of 2011 May River Watershed Action Plan Recommendations

As part of Task 2 of this project, the Team evaluated the recommendations put forth in the 2011 Action Plan. The purpose was to determine the status of the projects and policies and to make recommendations and adjustments that would align with current state of knowledge as described in Section 5.2 of this report.

Table 46: Action Plan Status and Recommendations

2011 Action Plan Initiative	Reference	Status	2020 Recommendations
Monitoring Data and Plan/Program	Table 3-3		
• Continue implementing monitoring program to monitor pollutant trends and evaluate effectiveness of BMPs		On-going	• Section 5.1 of May River Headwaters Model Report Strategies for Assessing Problems including in-house microbial source tracking, new bacteria monitoring locations, and new water flow monitoring
• Town of Bluffton Impervious Surface Delineation Project		On-going	• Continuously update impervious surface data (building footprints, roadways, paths, parking lots, stormwater ponds) to keep current
Town Policy and Ordinance Assessment	§3.3		
• Town of Bluffton Stormwater Design Manual • Beaufort County Stormwater Manual for Stormwater Best Management Practices	§3.3.1	In progress	• Adopt regional *Southern Lowcountry Post Construction Stormwater Ordinance and Design Manual* (2020) which places greater emphasis on managing stormwater based on watershed concerns related to water quality and flood prevention
Current Ordinances & Comprehensive Planning Review			
• Town of Bluffton Unified Development Ordinance		In progress	• Adopt and incorporate new regional *Southern Lowcountry Post Construction Stormwater Ordinance and Design Manual*
• Town of Bluffton Comprehensive Plan 2007 (Amended 2014)		In progress	• Prioritize conserving area to maintain low impervious areas in undeveloped sections of May River Headwaters. In Figure 10 of the May River Headwaters Modeling Report, there are 62 subcatchments that are currently 0-10% impervious area. • In redevelopment or CIP projects, consider tree planting as priority. Refer to Section 4.14 Tree Planting & Preservation in *Southern Lowcountry Stormwater Design Manual*
• Recommended Actions: o Continue coordination with the County to implement cohesive design requirements o Town to provide additional design information for runoff reduction (as opposed to a main focus on retention/detention)		In progress	• Adopt and incorporate new regional *Southern Lowcountry Stormwater Design Manual*. Included in the new guidance are requirements that pertain to channel erosion and culvert design: o The 10% Rule will require application of channel protection requirements downstream of development sites. Culvert and bridge conveyance capacities may need to be increased under the new 10%

○ Enhance section regarding culverts and bridge design to prevent the loss of natural in-stream or wetland attenuation that can reduce bacteria loads to May River ○ Protect channels and ditches from erosion by providing extended detention for the 1-year storm event			Rule and may result in daylighting existing conveyance and restoring previous lost wetland attenuation. ○ Post-development peak runoff control of the 2, 10, and 25-year 24-hour storms ○ Runoff reduction for the 95th percentile storm (1.95") • Develop program with the County to implement stormwater retrofit projects that fall outside of the Town's jurisdiction
Incentives to encourage volume or other water quality controls	§3.3.2		
• Promoting private entities (e.g. HOAs) to implement stormwater improvements • Reduce user fee via tax breaks/SW utility fee breaks to those who exceed the stormwater treatment requirements by a specific percentage • Increase quality of development/quality of life incentive by providing less nuisance flooding, cleaner water, increased pride, and more sustainable/green infrastructure		On-going	• Promote Stormwater Utility Fee Credit to private communities that implement BMPs above requirements • Establish public-private partnerships to implement projects/retrofits in areas identified by Water Quality Model outputs
Sustainable Development and Transfer or Purchase of Development Rights (TDR) Policies	§3.3.3		
• Encouragement of smart, sustainable, and environmentally-conscious growth within targeted locations of the Growth Framework Map • Provide more TDR opportunities to reduce impervious area introduced into the May River watershed • Ensure natural ground cover is maintained		On-going	• Continue to encourage protection of natural areas, especially forested areas, in concert with recommendations from the Historical Analysis of Water Quality, Climate Change Endpoints, and Monitoring of Natural Resources in the May River (Montie et al., 2019) and the regional *Southern Lowcountry Post Construction Stormwater Ordinance and Design Manual* (2020)
Land Acquisition Strategy/Condemnation Policy	§3.3.4		
• Develop land acquisition strategy for future potential stormwater projects		On-going	• Include parcel acquisition into 5-yr CIP Forecast based upon Water Quality Model outputs for targeted projects and for open space • Align with Beaufort County Green Space Plan

o Property acquisition will support a wide range of projects from pond modifications, new pond construction, and/or right of way expansion			
Sewer Policy	§3.3.5		
• Septic systems may be a source of bacteria loading • The Town should create a septic system ordinance to ensure long-term maintenance • Conduct a survey of septic users in the watershed • The Town should partner with Beaufort County and Beaufort-Jasper Water & Sewer Authority (BJWSA) to provide incentives for homeowners o Upgrading/replacing or retiring/converting systems • The Town should develop a program for inspections and education for homeowners on septic o Grant funding for pump outs and repair septic systems		Sewer Connection & Extension Policy (completed 2017) Septic to Sewer Conversion Program (completed 2018) Sewer Connection Ordinance and Amendment to require connection within 1 year of notification of available sewer (completed 2015 and 2018, respectively)	• XPSWMM model estimated the loading reduction in four project areas within the May River Headwaters where septic systems are proposed to be replaced by sanitary sewer. Even though two of the proposed projects had larger areas outside of the May River Headwaters, the model provides support for the recommendations to convert these areas. • The Town should regularly update the GIS recordkeeping for areas that are connected to sanitary sewer in order to get a more accurate representation of what areas remain on septic. • The Town should continue its joint efforts with BJWSA and Beaufort County to eliminate septic systems throughout the May River watershed.
Design Storm Recommendations for Development	§3.3.6		
• Discuss desire/feasibility for implementing an Aquatic Protection Standard • Perform more detailed monitoring throughout the watershed to determine outfall and rainfall volumes at various locations, to assist in determining actual runoff volumes versus predicted runoff volumes		Completed On-going	• Adoption of new regional *Southern Lowcountry Post Construction Stormwater Ordinance and Design Manual* will provide more restrictive requirements based on watershed impairment status and overall goal for Better Site Design • Specific monitoring recommendations included in the Headwaters Model Report for both bacteria, MST, and flow data
Wildlife Management Policy	§3.3.7		

• Perform a wildlife survey to determine the count/species of deer, hogs, raccoons, and coyotes within the watershed • Use the determined EMCs and loading information to obtain specific loading rates/concentrations throughout various portions of the watershed		Initial wildlife screening performed with USDA for deer population determined to not be nuisance level (completed 2012)	• Calibration for Headwaters model assigned fecal coliform EMCs by land use and were adjusted to fit model output to measured values from monitoring data. FC concentrations were also introduced into groundwater during calibration. In order of magnitude from least to greatest: Natural/open water, developed high intensity (sewer), developed open space, developed low/med intensity (sewer), and developed low/med intensity (septic).
Watershed Inventory	§3.4		
• Delineate May River Watershed	§3.4.1	Completed	• Headwaters model made use of delineated subwatersheds and subcatchments • Prepare a detailed GIS dataset of existing stormwater BMPs and their design criteria (drainage areas, water quality volume provided, etc.) to inform future XPSWMM model updates • Update subcatchment delineations as they may change with new development and modifications to site grading/topography
• Impervious surface map	§3.4.2	On-going	• The impervious surface map will need to be constantly updated as development increases. It may also be beneficial to indicate which impervious surfaces have been "restored" with practices such as permeable pavement retrofits. o Note that with the new *Southern Lowcountry Post Construction Stormwater Design Manual*, the surface area of a non-infiltrating BMP or its permanent pool shall be calculated as part of the impervious cover (See Eq. 3.2 in manual).
• Watershed Analysis o Use numerical modeling for prioritizing projects and assessing their anticipated improvements on the May River. This can include simple wash-off modeling through spreadsheets and/or complex hydrodynamic models that include event-mean concentrations, runoff volumes, and pollutant fate/transport mechanisms	§3.4.3	In progress	• Headwaters model utilized XPSWMM to identify bacteria hotspots based on land use and available monitoring data; this model can be improved and refined with future monitoring efforts as outlined in recommendations. • Periodically update XPSWMM model with completed stormwater projects and compare to water monitoring results • Consider recalibrating XPSWMM model with additional monitoring data collected in the future

o Long-term modeling approach should include dynamic modeling that can be calibrated to the water quality monitoring stations in the May River.			• Benefits of specific best management practices (structural and nonstructural) were modeled using the Center for Watershed Protection's Watershed Treatment Model (WTM)
Assessment and Implementation	§4.0		
• May River Watershed Indicators o Inventory of watershed sub-drainage basins and based on testing and sampling efforts	§4.1	Complete for FC	• While FC is the primary indicator of concern, additional indicators of watershed health should be considered, especially for MS4 compliance and based on SCDNR recommendations in the 2011 Action Plan to include nutrients and turbidity
• May River Water Quality Monitoring Program	§4.2		
o May River Water Quality Trend Analysis	§4.2.1		
▪ DNR Recommended Sampling Stations and Map ▪ DNR recommended Parameters: FC, TN, TP, turbidity ▪ DNR recommended sampling regimen	§4.2.1.1 §4.2.1.2 §4.2.1.3	Completed	• Modified for MS4 compliance
o Hot Spot Identification and Targeted Retrofits ▪ Hot spot identification map ▪ Hot spot attributes ▪ Matrix of types of targeted project/retrofit options • Septic/Sewer/Reuse Programs Projects • Wildlife Programs/Projects • Stormwater BMPs to address runoff from altered hydrology • Agricultural programs/projects • Pet waste programs • Runoff reduction • Education programs • Ordinance	§4.2.2 §4.2.2.1 §4.2.2.2 §4.2.2.3	On-going for hot spot map and attributes On-going for matrix and in progress as outputs of Water Quality Model	• Assess if additional hot spots exist for other pollutants, e.g. nutrients and turbidity • Focus for stormwater retrofit projects should be infiltration BMPs

• Incentives • Land acquisition			
o Pollutant Source: Septic ▪ Connect septic areas to sewer ▪ Septic inspection program ▪ Septic maintenance program ▪ Septic policy/ordinance ▪ Property owner association covenants and restrictions ▪ Septic system cleaning incentive program ▪ Septic retrofits	Table 4-1	Completed for ordinance and policies In progress for Town jurisdiction sewer extensions & connections In progress with County and BJWSA for watershed	• Continue to pursue projects and policies that will improve (through inspection, education, and upgrades) or replace existing septic systems.
o Pollutant Source: Wildlife/Domestic Animals ▪ Physical barriers ▪ Dog waste signs ▪ Expand forest buffers ▪ Reduce food sources in developed areas (e.g. trash cans); include in nuisance ordinance ▪ Re-introduction of predators of problem species ▪ Hunting/culling ▪ Wildlife corridors	Table 4-1	Initial wildlife screening performed with USDA for deer population and determined to not be nuisance level (completed 2012) On-going domestic pet education	• Continue programs with Lowcountry Stormwater Partners to reduce pet waste in the watershed (providing waste stations and bags)
o Pollutant Source: Altered Hydrology ▪ Regional pond ▪ Wetland restoration/retrofit ditching ▪ Retrofit lagoons/ponds ▪ Incentives to encourage LID/retrofits ▪ Runoff reduction ▪ Design storm recommendations/alternative design storms	Table 4-1	In progress with Water Quality Model outputs	• Adoption of new regional *Southern Lowcountry Post Construction Stormwater Ordinance and Design Manual* will provide more restrictive requirements based on watershed impairment status and overall goal for Better Site Design. Additionally, the new requirements emphasize utilizing BMPs that promote infiltration and evapotranspiration to reduce the volume of stormwater leaving a site (and stormwater ponds will not provide runoff reduction credit).

o Pollutant Source: Varying ▪ Education ▪ Horse manure management & BMPs ▪ Individual homeowner BMPs ▪ Unified Development Ordinance Amendments ▪ Land Acquisition ▪ Development Agreements/Incentives ▪ Transfer of Development Rights ▪ Solar Aerators for existing ponds	Table 4-1	On-going education for all sources via Lowcountry Stormwater Partners	• Partner with Clemson Extension agents to provide educational programming and resources for small horse farms in May River Headwaters (teach about proper disposal and/or composting of manure) • Partner with Clemson Extension to encourage homeowners to certify their properties as a Carolina Yard by planting natives, reducing fertilizer application, and utilizing rainwater harvesting as an irrigation source. • Partner with Clemson Extension to encourage homeowners to install rain gardens to help manage stormwater on their properties. • Work with HOAs and golf course communities to maximize the use of stormwater ponds as irrigation sources.
o Map of Targeted Project/Retrofit Options, ▪ Smaller sized waterbodies under tidal influence ▪ Undeveloped sub-watersheds ▪ Developed areas	§4.2.2.4	In progress with Water Quality Model outputs	• Target project areas include those with high bacteria loading, high impervious areas, and septic systems. See Section 5.4 in May River Model Report for details.
• Retrofit Opportunities	§4.3		
o Identification of Types of Projects	§4.3.1	In progress with Water Quality Model outputs	• See section 5.2 of May River Watershed Model Report
o Prioritizing of Structural Projects in Need of Retrofit ▪ BMPs effectiveness ▪ Adjacent sampling station water quality data ▪ Ease of implementation ▪ Available area ▪ Construction costs ▪ Schedule ▪ Partnering ▪ Feasibility ▪ Ability to complement local culture ▪ Cooperation/incentives for private property owners	§4.3.2	In progress with Water Quality Model outputs	• See Section 5.4.3 of May River Watershed Model Report

o Prioritizing of Non-Structural Projects ▪ Similar to structural project prioritization process	§4.3.3	In progress with Water Quality Model outputs	• Section 5.2.3 of the May River Watershed Model Report describes Policies, Programs, and Partners for non-structural controls to address bacteria impairments
o Identification of Specific Projects for Retrofit	§4.3.4	In progress with Water Quality Model outputs	• See Section 5.4.2 of the May River Watershed Model Report describes 11 stormwater retrofit project opportunities
o Recommended BMPs ▪ A: Future New Riverside area (3 new ponds) ▪ B: Kenzie Park Outfall (new pond) ▪ C: Rose Dhu Creek (new pond) ▪ D: Buckwalter Community Park/The Farm (ditch modifications) ▪ E: Stoney Crest (earthen ditch blocks/wetland restoration) ▪ F: Hampton Lake Retrofit (pond modification) ▪ G: Lakepoint Drive (pond modifications) ▪ H: Pinecrest (pond modifications) ▪ I: Pinecrest (pond modifications) ▪ J: Town Property (expand existing pond) ▪ K: Guerrard/Wharf Street (modify existing pond/construct new ponds) ▪ L: Gascoigne Bluff (construct new ponds) ▪ M: Traver Tract (modify existing ponds) ▪ N: Ditch in Hampton Lake (construct earthen ditch blocks/wetland restoration)	Table 4-2	In progress with Water Quality Model outputs	• This report does not recommend construction of new ponds, but rather presents information for how existing ponds can be evaluated to be made more "bacteria neutral." • This report recommends that the Town conduct further field investigations to collect more detailed information for existing ponds and ditches for retrofit opportunities. See Tables 43 and 44 • Coordinate with Department of Transportation (local, county, state) to implement additional stormwater retrofits within limits of roadway improvement or maintenance projects.
o General Stormwater Project Concepts ▪ Oscar Frazier Community Park: pet waste management, vegetates swales and rain gardens, additional pervious pavement, rain tank ▪ General Town & County Facilities: rain gardens, rain barrels & cistern, pervious pavement,	Table 4-3	In progress with Water Quality Model outputs	• Stormwater BMP Retrofit Projects described in Section 5.4 of the May River Headwaters Modeling Report

disconnect downspouts from storm drains, native vegetation ▪ Road BMPs: retrofit medians and swales to increase perviousness			
o Projects Included in FY2012 Town Plan	Table 4-4	On-going	• Based upon Water Quality Model outputs, new projects included in 5-yr. CIP Forecast
o Projects for Newer Neighborhood Developments: The Farm, Hampton Hall, Hampton Lakes, Rose Dhu Creek Plantation ▪ Pond retrofit ▪ Wildlife controls ▪ Rainwater harvesting ▪ Pet waste stations/other pet waste programs	Table 4-5	In progress with Water Quality Model outputs	• Coordinate with property management companies to identify capital improvement projects that are forecasted, to allow for incorporation of stormwater retrofit opportunities • Offer discounted trees to residents to encourage "reforestation" of their yards
o Projects for Older Neighborhood Developments: Gascoigne Bluff, May River Plantation ▪ Wildlife controls ▪ Septic programs ▪ Rainwater harvesting ▪ Regional ponds ▪ Retrofit ditches ▪ End of pipe retrofits ▪ Pet waste stations/other pet waste programs ▪ Wetland retrofit	Table 4-6	In progress with Water Quality Model outputs	• Coordinate with property management companies to identify capital improvement projects that are forecasted, to allow for incorporation of stormwater retrofit opportunities • Offer discounted trees to residents to encourage "reforestation" of their yards
o Project Development in all Neighborhoods ▪ Promote water conservation practices ▪ Provide community education for pet waste pick up ▪ Promote individual LID projects such as rain barrels and rain gardens on residential lots ▪ Hold stakeholder meetings to encourage HOAs to periodically and consistently review regulations and promote new regulations	Table 4-7	In progress with Water Quality Model outputs On-going education via Lowcountry Stormwater Partners	• Continue education efforts with Lowcountry Stormwater Partners

o Review/Update Development Policies ▪ Include a temporal clearing guide ▪ Reduce overall imperviousness by implementing pervious pavement ▪ Promote implementation of stormwater harvesting ▪ Coordinate with developers and landowners to promote transfer or purchase of development rights transactions	Table 4-8	On-going	• Adoption of new regional *Southern Lowcountry Post Construction Stormwater Ordinance and Design Manual* will provide more restrictive requirements based on watershed impairment status and overall goal for Better Site Design • Address how predevelopment silviculture impacts hydrology pre and post conditions analysis.

5.4 Development of 2020 May River Watershed Action Plan Project Recommendations

The purpose of this section is to quantify the potential benefits of 2020 May River Headwaters Watershed projects on bacteria loading in the May River Headwaters watersheds.

5.4.1 State of Knowledge

Fecal indicator bacteria (FIB) do not correlate well with the occurrence of pathogens, and they do not identify the source of the contamination. Additionally, many studies – including monitoring efforts by the Town of Bluffton – have documented that FIB can colonize and regrow in biofilms and sediments in the storm drainage system. These constraints of FIB further limit the ability to track the original source of contamination (Burkhart, 2012). In general, human sewage contamination presents the greatest health risk and is a controllable source (fix underperforming septic systems and/or sanitary sewer conveyance systems).

Residential land uses, which are predominant in the May River Headwaters, tend to produce high bacteria loading for a myriad of contributing factors including leaking septic tanks, pet waste pick-up behavior, as well as turf management and erosion control practices (Wood, 2018). Pollutants in stormwater runoff, such as bacteria, can be managed through both structural and non-structural methods.

Available information from research indicates that BMP efficiency is variable and dependent on the design, maintenance, and other factors. For example, in some cases a net export of microbes can result due to improper maintenance, regrowth of microbes in the BMP, resuspension during storm events, or direct wildlife deposits (Characklis et al., 2009). Information regarding removal rates of FIB in the International BMP Database (Clary et al., 2010) are variable and dependent on the following, 1) season in which the FIB were quantified; 2) stormwater volume and flows; and 3) the type of FIB being measured. Removal values in coastal SC will most likely be lower than those included in the International BMP Database, which has many studies based on the West Coast. This is primarily due to the following, 1) SC temperature is higher during most seasons than in west coast environments; 2) SC water sources tend to be blackwater and tannic water, which reduces light penetration; and 3) persistent forms of FC are known to grow in the sediments of systems in SC. Furthermore, research has called attention to the nature of temperature-warm, nutrient-rich, stagnant BMPs systems that appear to serve as a reservoir of FIB and at times may also preferentially grow the fecal indicator bacteria.

The International Stormwater BMP database contains approximately 600 pairs of influent and effluent data for fecal coliforms and E. coli. across multiple states. Clary et al. (2008) analyzed the fecal coliform and E. coli data and showed that swales and detention basins did not appear to effectively reduce FIB in effluent samples. Datasets for wetlands and manufactured devices were not of adequate size to draw meaningful conclusions, but sometimes these systems showed bacterial growth. The authors concluded that the ability of BMPs to reduce FIB varies widely across BMPs. No single BMP appears to consistently reduce FIB concentrations. Among the BMPs, retention pond and media filters appeared to show some positive trends, but these were not across the board.

Additionally, high removal efficiency does not always guarantee attainment of bacteria standards when inflow concentrations are high (Wood, 2018). Across the southeastern region, there is a movement away from stormwater ponds in favor of emphasizing other practices that encourage runoff reduction, which is defined as "the total annual runoff volume reduced through canopy interception, soil infiltration, evaporation, transpiration, rainfall harvesting, engineered infiltration, or extended filtration."

5.4.2 Process to Determine Recommended Projects

Subcatchments within each of the four major subwatersheds (Duck Pond, Palmetto Bluff, Rose Dhu Creek, and Stoney Creek) were targeted for analysis based on concerns related to geospatial data (such as existence of septic systems or large impervious areas) as well as results from the XPSWMM water quality model (largest total FC loading or loading normalized for the subcatchment area). Table 46 lists the top ten subcatchments for each of four categories: total annual load, normalized annual load, total impervious area (acres) and total impervious area (as a percent). In total, 23 subcatchments are included in Table 46. Several subcatchments, such as SC112, were included in several categories. This exercise served as an initial screening for potential project sites. However, an initial screening of these 23 subcatchments revealed that the potential for retrofit projects would be limited due to a variety of factors, including perceived difficulty gaining permission to alter private property and existing large water features. One anomaly on the list was PB17; although the Palmetto Bluff subwatershed had good water quality overall, the normalized load was high and most likely due to the relatively small size of the watershed and large area of developed open space (e.g. turfgrass). Developed open space has the third highest calibrated FC loading rate (refer to Table 32 in §3.2.2 of this report).

Furthermore, large ponds constitute large impervious areas in several subcatchments (such as SC103, SC110, SC112, SC119, SC143, SC162, SUB-RD-17). There are several problems associated with ponds. First, they do not promote the infiltration of precipitation, and thus do not provide any runoff reduction. Stormwater enters the system and leaves at a controlled flowrate, which is advantageous for flood protection but may promote the persistence of FIB downstream of the practice (as has been documented in the literature and the Town's monitoring data). Secondly, when the amenity ponds are very large in a subcatchment, there may not be sufficient room to allow for other infiltration practices to be retrofitted on site.

Table 47: Top XPSWMM Model Result Concerns by Subcatchment

Subcatchment	Total Annual Load (# FC)	Normalized Annual Load (# FC/acre)	Total Impervious Area (acres)	Total Impervious Area (%)
PB17		9.84E+10		
SC103	2.17E+13	1.38E+11		
SC104		1.47E+11		
SC106	2.51E+13	9.62E+10	54.48	
SC108 [B]	2.17E+13	1.38E+11		56
SC110				66
SC111 [B]				28
SC112	2.06E+13	1.02E+11	58.95	29
SC116	1.71E+13		163.72	
SC119				33
SC124 [A]		1.83E+11		
SC142 [B]		1.95E+11		39
SC143 [B]				29
SC162	1.71E+13		59.92	39
SUB-RD-06 [B]			100.14	
SUB-RD-08 [B]			67.19	
SUB-RD-09	3.09E+13	1.25E+11		
SUB-RD-10			105.56	
SUB-RD-11	2.66E+13			
SUB-RD-12	1.64E+13	1.06E+11		
SUB-RD-13 [B]			53.49	40
SUB-RD-15 [B]			87.68	
SUB-RD-17	2.66E+13		76.46	46

A: subcatchment included in septic-to-sewer conversion project analysis

B: subcatchment included in stormwater BMP retrofit project analysis

In order to identify other potential projects, the project team then targeted the largest non-BMP impervious areas in the Headwaters watershed, such as parking lots and building footprints (48 and 49). The importance of mitigating impervious surfaces in a tidal creek watershed (such as the Headwaters of the May River) is underscored by local research (Holland et al, 2004; Sanger et al., 2008; Sanger et al., 2015). As previously noted, these studies have documented measurable anthropogenic impacts on natural systems and tidal creeks as a result of increases in impervious area in response to population growth.

Table 48: Largest Parking Lots in May River Headwaters

Location	Size (acres)	Ownership	Subcatchment	Hydrologic Soil Group (HSG)
Bluffton HS	4.88	Public	SUB-RD-13	A/D
Kings Summer Isle Apartments	4.15	Private	SUB-RD-03	A, A/D
Bluffton Elementary/HE McCracken MS	3.46	Public	SUB-RD-13/14	A/D
Lowcountry Community Church	2.75	Private	SUB-RD-6/13	A/D
Hampton Hall Club 1	2.71	Private	SUB-RD-17	A, B/D
Hampton Hall Club 2	2.51	Private	SUB-RD-17	A, B/D
Buckwalter Recreation Center	2.68	Public	SUB-RD-8	A/D
SCE&G/Dominion Energy	2.56	Private	SC-111	A
Cross Schools	2.54	Private	SUB-RD-5/8	A/D
Bluffton Fire Station 37	1.98	Private	PB20/27	A/D, B

Table 49: Largest Building Footprints in May River Headwaters

Location	Size (acres)	Ownership	Subcatchment	HSG
May River High School*	4.27	Public	SC-142	B/D
Bluffton High School*	3.35	Public	SUB-RD-13	A/D
H.E. McCracken Middle School*	3.29	Public	RD-8, 13, 14, 15	A/D
Calvary Training Center (stables)*	2.04	Private	SC157	A/D, B
Bluffton Elementary*	1.99	Public	RD-13, 14	A/D
Pritchardville Elementary*	1.77	Public	SC111	A
Cross Schools	1.75	Private	SUB-RD-05	A/D
Lowcountry Community Church*	1.49	Private	SUB-RD-06	A/D
Benton House of Bluffton*	1.34	Private	SC105	B/D
Arena near Longfield Stables	1.20	Private	PB-10	A/D
Bluffton Early Learning Center	1.14	Public	SUB-RD-14	A/D
Buckwalter Recreation Center*	1.1	Public	SUB-RD-08	A/D
Boys and Girls Club of Bluffton	0.56	Public	SUB-RD-14	A/D

After utilizing GIS analysis to screen potential projects, based on subcatchment FC loads, soils, impervious areas, and parcel ownership, the Project Team in consultation with the Town selected eleven (11) project sites for analysis of potential retrofit options, and four (4) septic to sewer conversion projects in the May River Headwaters (Table 50).

Table 50: Selected Projects for Analysis of Septic to Sewer Conversion and Stormwater Retrofits

Project Type	Name
Septic to Sewer	Cahill
Septic to Sewer	Gascoigne
Septic to Sewer	Stoney Creek
Septic to Sewer	Pritchardville
Stormwater Retrofit	Bluffton Early Learning Center (BELC)
Stormwater Retrofit	Boys and Girls Club of Bluffton (BGC)
Stormwater Retrofit	Benton House (BH)
Stormwater Retrofit	Bluffton High School (BHS)
Stormwater Retrofit	Buckwalter Recreation Center (BRC)
Stormwater Retrofit	Lowcountry Community Church (LCC)
Stormwater Retrofit	McCracken Middle School/Bluffton Elementary School (MMSBES)
Stormwater Retrofit	May River High School (MRHS)
Stormwater Retrofit	One Hampton Lake Apartments (OHLA)
Stormwater Retrofit	Pritchardville Elementary School
Stormwater Retrofit	Palmetto Pointe Townes (PPT)

5.4.3 Septic to Sewer Conversion Projects

Section 3.3.5 Sewer Policy of the Action Plan includes discussions about how septic systems may be a source of bacteria loading in the May River watershed. Recommended actions included discussion of septic policies, such as required maintenance and repairs, as well as converting to sanitary sewer. Additional projects the Town has undertaken include the May River Watershed Sewer Master Plan to convert septic to sewer throughout the May River watershed regardless of Town or County jurisdiction. There is concern that converting areas with septic systems to sanitary sewer could facilitate future development – the results of which could mean increased development (loss of natural areas and increases in impervious areas). The Project Team believes the Town and Beaufort County are already well-situated to discourage these types of unintended consequences by enforcing the new *Southern Lowcountry Stormwater Design Manual* and its stringent requirements for new development and redevelopment in watersheds that include bacteria impairments and/or shellfish harvesting. Additionally, Beaufort County, in conjunction with property owners, established the May River and Alljoy Community Preservation Districts to protect current density regardless of sewer extension.

An analysis of the potential FC reduction impact of four of these septic to sewer conversion projects (Cahill, Gascoigne, Stoney Creek, and Pritchardville, as shown in Figure 45) was conducted using the XPSWMM model. These projects would overlap with 42 subcatchments in the Stoney Creek watershed and 11 in Rose Dhu Creek.

The estimated cost of these projects provided by Beaufort-Jasper Water and Sewer Authority (BJWSA) was $20.8 million. All sewer projects in the County's jurisdiction assume a 3-party cost share between BJWSA, Beaufort County, and the Town of Bluffton.

As described in Section 2.8 in this report, the land use categories for low and medium density development are separated into two categories to distinguish between areas that are connected to sanitary sewer or septic systems. The analysis of the impact of the septic to sewer projects involved altering the inputs for low/medium intensity development land use in the XPSWMM model: first, removing the land use in the "low/medium septic" category and then adding that area to the "low/medium sewer" category.

Based upon the model outputs of FC load reductions, the Project Team recommends the Town continue to partner with Beaufort County and Beaufort-Jasper Water & Sewer Authority (BJWSA) to systematically eliminate septic systems throughout the watershed in the areas beyond the scope of this project and ensure critical infrastructure is located or designed with possible future sea level rise scenarios in mind.

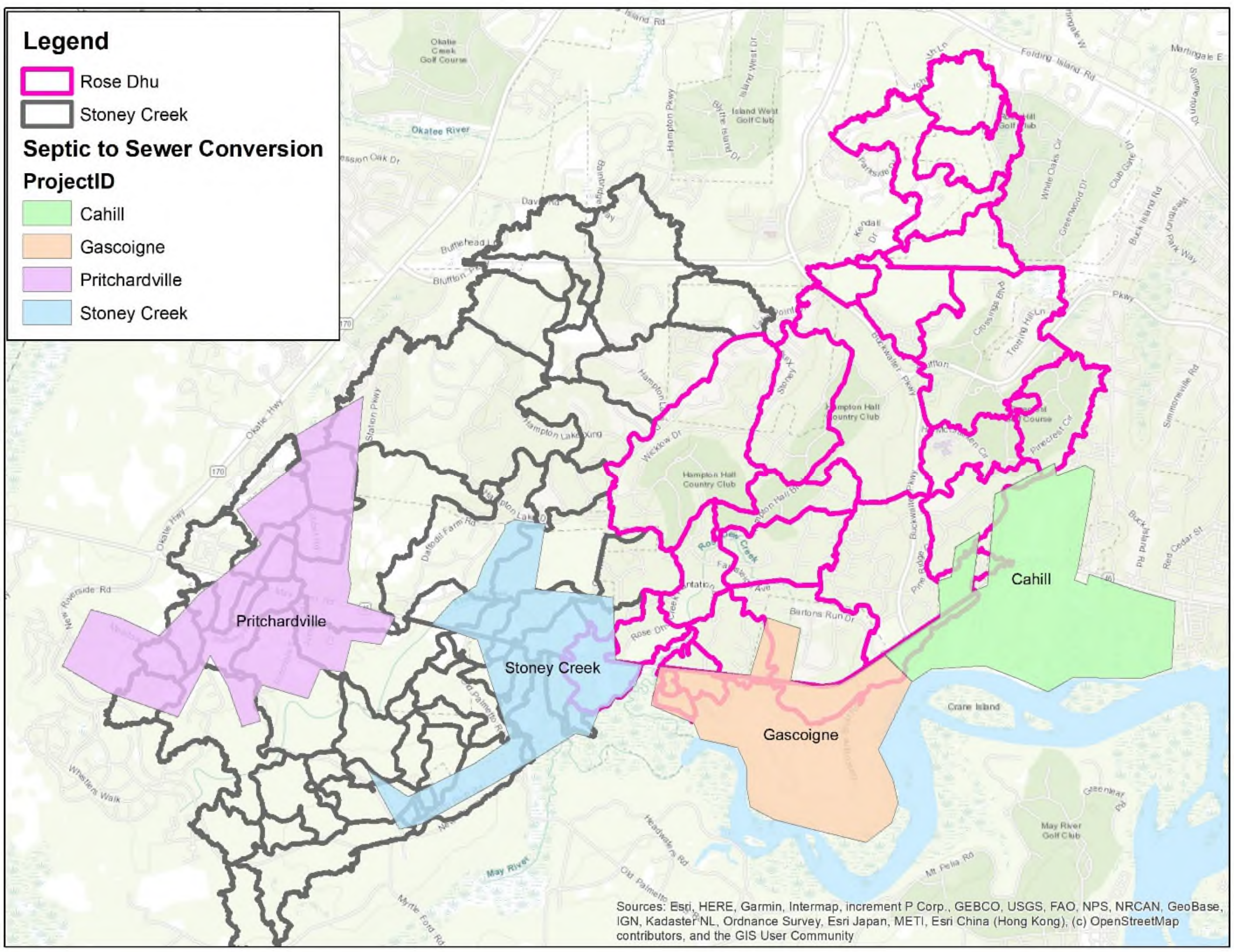

Figure 45. Septic to Sewer Conversion Projects in the May River Headwaters

5.4.3.1 Cahill

The Cahill area (820 acres) overlaps with a small section (78 acres) of the Rose Dhu Creek subwatershed, specifically three subcatchments as listed in Table 51. Of those three subcatchments, only one has properties with septic systems according to available data (see Figure 12 in Section 2.4.3 of this report). The XPSWMM model predicts that conversion of these properties to sanitary sewer would result in a reduction of 1.09×10^{10} FC bacteria (or about 0.11% of the FC load in these three subcatchments). Please note that the overall Cahill project impacts a much larger area outside of Rose Dhu Creek, in section of the Town that were not included as part of the Headwaters analysis in this study. There are 114 parcels in the Cahill project area, of which 75 parcels (including parts of 12 parcels in the Rose Dhu Creek subwatershed specifically) are not currently connected to sanitary sewer. Therefore, this calculation does not completely capture the full benefit of FC reduction for the entire Cahill septic to sewer project.

Table 51: Bacteria Load Reduction for Cahill Septic to Sewer Conversion Projects

Subcatchment	2018 Load with Septic (# FC)	2018 Load with Sewer (# FC)	Load Reduction (# FC)
SUB-RD-14	1.90E+12	1.90E+12	0.00E+00
SUB-RD-15	4.17E+12	4.17E+12	0.00E+00
SUB-RD-22	4.19E+12	4.18E+12	1.09E+10
Total	1.03E+13	1.02E+13	1.09E+10

5.4.3.2 Gascoigne

Similarly, the Gascoigne area (721 acres) overlaps with a small area (187 acres) of the Rose Dhu Creek subwatershed along May River Road, as listed in Table 52. All but one of these subcatchments include properties with septic systems according to available data (see Figure 12 in Section 2.4.3 of this report). The XPSWMM model predicts that conversion of these properties to sanitary sewer would result in a reduction of 3.32×10^{11} FC bacteria (or about 1.03% of the FC load in these three subcatchments). Please note that the overall Gascoigne project includes additional areas outside of Rose Dhu Creek, in section of the Town that were not included as part of the Headwaters analysis in this study. There are 78 parcels in the Gascoigne project area, and all parcels (including parts of 40 parcels in the Rose Dhu Creek subwatershed specifically) are not currently connected to sanitary sewer. Therefore, this calculation does not completely capture the full benefit of FC reduction for the entire Gascoigne septic to sewer project.

Table 52: Bacteria Load Reduction for Gascoigne Septic to Sewer Conversion Projects

Subcatchment	2018 Load with Septic (# FC)	2018 Load with Sewer (# FC)	Load Reduction (# FC)
SUB-RD-16	1.23E+13	1.21E+13	2.23E+11
SUB-RD-18; SUB-RD-19	6.08E+12	6.02E+12	6.00E+10
SUB-RD-20; SUB-RD-21; SUB-RD-23	4.75E+12	4.74E+12	1.30E+10
SUB-RD-22	4.19E+12	4.18E+12	1.09E+10
SUB-RD-24; SUB-RD-27	4.66E+12	4.63E+12	2.46E+10
SUB-RD-28	1.20E+11	1.20E+11	0.00E+00
Total	3.21E+13	3.17E+13	3.32E+11

5.4.3.3 Stoney Creek

The Stoney Creek conversion project area (687 acres) is completely contained within the water quality model area and includes 141 parcels. These parcels overlap with 26 subcatchments in the Stoney Creek subwatershed and six subcatchments in the Rose Dhu Creek subwatershed, as listed in Table 53. Thirteen of these subcatchments did not have septic systems according to available data (see Figure 12 in Section 2.4.3 of this report). The XPSWMM model predicts that conversion of these properties to sanitary sewer would result in a reduction of 1.00×10^{13} FC bacteria (or about 15% of the FC load in these specific subcatchments).

Table 53: Bacteria Load Reduction for Stoney Creek Septic to Sewer Conversion Projects

Subcatchment	2018 Load with Septic (# FC)	2018 Load with Sewer (# FC)	Load Reduction (# FC)
SC101	5.45E+11	5.45E+11	0.00E+00
SC102	1.62E+12	7.09E+11	9.13E+11
SC117	1.73E+12	1.73E+12	8.95E+08
SC118; SC147	6.63E+12	4.54E+12	2.09E+12
SC125	2.59E+12	1.31E+12	1.28E+12
SC126	1.15E+12	5.70E+11	5.78E+11
SC127	2.54E+11	2.08E+11	4.59E+10
SC128	1.93E+12	6.95E+11	1.24E+12
SC129	2.78E+12	2.78E+12	0.00E+00
SC130	5.13E+12	1.74E+12	3.39E+12
SC136; SC138	3.32E+12	3.32E+12	0.00E+00
SC137	7.77E+11	7.77E+11	0.00E+00
SC141	1.43E+12	1.43E+12	0.00E+00
SC145	4.54E+12	4.49E+12	5.00E+10
SC146	3.98E+11	3.98E+11	0.00E+00
SC148	5.49E+12	5.49E+12	0.00E+00
SC149	2.27E+12	2.26E+12	6.77E+09
SC150	1.19E+12	1.19E+12	0.00E+00
SC151	4.53E+11	7.91E+10	3.74E+11
SC152	1.25E+11	1.25E+11	0.00E+00
SC154	1.90E+11	1.90E+11	0.00E+00

Subcatchment	2018 Load with Septic (# FC)	2018 Load with Sewer (# FC)	Load Reduction (# FC)
SC155	1.12E+12	1.12E+12	0.00E+00
SC156	5.66E+12	5.66E+12	5.30E+09
SC158; SC159	1.76E+12	1.76E+12	0.00E+00
SUB-RD-20; SUB-RD-21; SUB-RD-23	4.75E+12	4.74E+12	1.30E+10
SUB-RD-22	4.19E+12	4.18E+12	1.09E+10
SUB-RD-24; SUB-RD-27	4.66E+12	4.63E+12	2.46E+10
Total	6.67E+13	5.67E+13	1.00E+13

5.4.3.4 Pritchardville

The Pritchardville conversion project area (997 acres, including 539 parcels) is completely contained in the water quality model area, and overlaps with 20 subcatchments in the Stoney Creek subwatershed, as listed in Table 54. Nine of these subcatchments did not have septic systems according to available data (see Figure 12 in Section 2.4.3 of this report). The XPSWMM model predicts that conversion of these properties to sanitary sewer would result in a reduction of 2.43×10^{13} FC bacteria (or about 26% of the FC load in these specific subcatchments).

Table 54: Bacteria Load Reduction for Pritchardville Septic to Sewer Conversion Projects

Subcatchment	2018 Load with Septic (# FC)	2018 Load with Sewer (# FC)	Load Reduction (# FC)
SC-107	8.88E+11	6.46E+11	2.42E+11
SC-109	2.01E+12	1.94E+12	7.55E+10
SC-111	1.69E+12	1.69E+12	0.00E+00
SC-114-120	1.15E+13	1.15E+13	0.00E+00
SC-115	1.12E+12	1.05E+12	7.33E+10
SC-116-162	1.71E+13	1.71E+13	0.00E+00
SC-121	3.30E+12	1.14E+12	2.16E+12
SC-122	4.88E+12	1.39E+12	3.49E+12
SC-123	1.75E+12	1.75E+12	0.00E+00
SC-124	1.18E+13	4.80E+11	1.13E+13
SC-131	1.27E+12	1.27E+12	0.00E+00
SC-132	8.37E+12	4.77E+12	3.61E+12
SC-133-140	1.12E+13	1.07E+13	4.58E+11
SC-148	5.49E+12	5.49E+12	0.00E+00
SC-156	5.66E+12	5.66E+12	5.30E+09
SC-157	2.16E+12	8.58E+11	1.30E+12
SC-160	1.08E+12	1.08E+12	0.00E+00
SC-161	2.17E+12	6.14E+11	1.56E+12
Total	9.35E+13	6.92E+13	2.43E+13

5.4.4 Stormwater BMP Retrofit Projects

These projects were selected in consultation with the Town and evaluated using the Watershed Treatment Model (WTM). The project team in consultation with the Town decided that this spreadsheet-based model allowed for flexibility to quickly analyze and evaluate a variety of stormwater BMPs, including permeable pavement, bioretention, green roofs, rainwater harvesting, filters, and infiltration trenches and chambers. The decision not to model BMPs in XPSWMM was the result of extensive consultation with the software developer's technical support advisors, who emphasized that the many processes that affect bacteria, such as temperature, light, nutrients, wind, etc., are not part of XPSWMM. Sanitary mode, which was utilized for the May River Headwaters Water Quality Model, has better water quality capabilities, but the hydraulics routing is simplified.

Adding BMPs to the XPSWMM model does not deliver a user-friendly model. Ultimately, if the model is forced to represent various BMPs, the resultant model would be difficult for an end-user to understand and to adjust. For example, infiltration BMPs are simply input as another sub-area within a given subcatchment that have flow directed to it; a user unfamiliar with the development of the model would not intuitively be able to distinguish between a BMP and an open space. Furthermore, the subcatchments that were established for the May River Headwaters subwatersheds (Duck Pond, Palmetto Bluff, Rose Dhu Creek, and Stoney Creek) were small enough to provide accurate representations of runoff and bacteria loading in the subwatersheds, but were too large to make distinctions for site-scale projects. In order to allow all users to evaluate the effectiveness of BMPs it was determined that use of the WTM would be the most accommodating option.

In contrast, the WTM is a simple, spreadsheet-based tool that evaluates loads from a wide range of pollutant sources (sediment, nutrients, and runoff volume) on an annual basis and incorporates a full suite of watershed treatment options (Caraco, 2013). Additionally, the model incorporates many simplifying assumptions that allow the watershed manager to assess various programs and sources that are not typically tracked in more complex models (such as public education efforts related to pet waste or street sweeping).

For each project site, the first step before setting up the WTM was to calculate the stormwater retention volume (SWRv) for these sites. The SWRv requirement is defined in the new *Southern Lowcountry Stormwater Design Manual* (see Section 3.5 and 3.7 in the design manual). The May River watershed is located in a Bacteria and Shellfish Watershed Protection Area, which requires the 95th percentile storm (1.95") to be retained on site. The equation for calculating the required SWRv is listed below, and the coefficients are listed in Table 55.

$$SWRv = \frac{P \times [(Rv_I \times I) + (Rv_c \times C) + (Rv_N \times N)]}{12}$$

Where:

$SWRv$ =	Volume required to be retained (cubic feet)
P =	Depth of rainfall event for the designated watershed protection area (85th or 95th percentile rain event)
Rv_I =	Runoff coefficient for impervious cover and BMP cover based on SCS hydrologic soil group (HSG) or soil type
I =	Impervious cover surface area (square feet)

Rv_C = Runoff coefficient for compacted cover based on soil type

C = Compacted cover surface area (square feet)

Rv_N = Runoff coefficient for forest/open space based on soil type

N = Natural cover surface area (square feet)

12 = Conversion factor (inches to feet)

Table 55: Runoff Coefficients for Land Use and Soil Type

	Rv Coefficients			
	A soils	**B Soils**	**C Soils**	**D Soils**
Forest/Open Space (Rv_N)	0.02	0.03	0.04	0.05
Managed Turf (Rv_C)	0.15	0.20	0.22	0.25
Impervious Cover (Rv_I)	0.95	0.95	0.95	0.95
BMP	0.95	0.95	0.95	0.95

Table 56 summarizes both the full SWRv (as a product of impervious surfaces, compacted cover, and natural areas on the sites) and a reduced SWRv (that only considers the impervious surfaces that are part of the hardscape, e.g. building footprints, sidewalks, roads, and parking lots, and not ponds). Because these projects are retrofits, the Town desired flexibility in mitigating the negative impacts of impervious surfaces and adhering to the new design standards.

Table 56: Stormwater Retention Volume Calculations

Project	HSG	Drainage Area (ft^2)	Impervious Surfaces (I) (ft^2)	Compacted Cover (C) (ft^2)	Natural Areas (N) (ft^2)	Full SWRv (ft^3)	Reduced SWRv (ft^3)
BELC	D	347,609	127,988	99,752	119,869	24,784	19,250
BGC	D	514,444	151,578	74,923	287,942	28,783	12,874
BH	D	309,712	124,102	52,272	133,337	22,365	16,227
BHS	D	2,358,774	1,190,871	377,665	790,238	205,604	176,167
BRC	D	4,653,079	371,316	621,601	3,660,162	112,313	54,820
LCC	D	707,850	278,385	341,946	87,519	57,578	41,262
MMSBES	D	1,799,464	777,728	179,032	842,704	134,182	110,628
MRHS	D	2,498,166	1,006,027	687,812	804,326	189,783	146,295
OHLA	D	1,287,198	530,987	687,812	68,399	110,469	81,799
PES	A	1,068,527	327,096	60,984	680,447	54,193	46,549
PPT	A	807,167	314,078	226,948	266,141	54,883	44,853

After the required SWRv was calculated, the next step was to evaluate the potential structural stormwater BMPs that could be integrated into the site. The goal of the stormwater BMP retrofit projects was to try to achieve the reduction of the SWRv to the maximum extent practicable; however, it should be noted that the actual designs of these projects may have more or less capacity depending on site constraints (infiltration rate, utility conflicts, etc.). A conceptual sketch of suitable BMPs was created showing the relative size and location of each practice. The potential water quality volume was calculated based on surface area and storage space (e.g. pore space in filter media or stone reservoir). This value was optimized to provide treatment of the SWRv, with the assumption that only two sites had in-situ soil infiltration rates that would support fully-infiltrating BMPs (HSG A and B soils); the remaining nine sites were assumed to require an underdrain, which results in a lower runoff reduction. For example, in HSG C and D soils, permeable pavement (30% runoff reduction) and bioretention (60% runoff reduction) can still be utilized.

The final step was to evaluate benefits of these projects in WTM. Because the XPSWMM model had already calculated the loads for each of the subwatersheds, and some project sites crossed multiple subcatchment boundaries (see BGC, BH, MMSBES, and OHLA) , the WTM model was only used to evaluate the potential benefits (load reductions) associated with 11 selected project sites. This procedure was followed to set up the WTM spreadsheet for each retrofit project site:

1. Delineate the project boundary in GIS by tracing the parcel boundary. Input as watershed area (acres) on "sources" tab in WTM.
2. Input annual rainfall (inches) as 42.95 (the same amount used for 2018 XPSWMM model) on "sources tab" in WTM.
3. Determine the land use (from 2016 NLCD) and soil hydrologic groups (from NRCS soils). Note, these are required initial parameters in WTM to calculate loads associated with land use; however, the calibrated XPSWMM load for the entire subcatchment will be the reference for the benefits associated with BMP retrofits calculated in WTM.
    a. On "Sources" tab, under "Primary Sources – Land Use" input area in acres for each land use category.
    b. On "Sources" tab, under "Soils Information" input the fraction of soils (as a percent) in each of the four hydrologic soils groups; assume that average depth to ground water is 3-5 feet for all project areas.
4. On Defaults tab – all BMP efficiencies were adjusted, in consultation with the Center for Watershed Protection (CWP), to reflect the values from Table 3.3 (Pollutant Removal Efficiencies of Structural BMPs) in the *Southern Lowcountry Stormwater Design Manual.* This involved the assumption that a specific BMP will have the same runoff reduction regardless of Hydrologic Soil Group (HSG), and a conversion table provided by CWP (because the off-the-shelf version of WTM assumes that removal efficiency is a combination of soil HSG and BMP, whereas the *Southern Lowcountry Stormwater Design Manual* assumes that runoff reduction and BMP performance are the same regardless of soil).
    a. Four BMPs have identical performance efficiencies as a result of being credited with 100% removal of TSS, TN, and bacteria and 100% runoff reduction: bioretention with no underdrain, enhanced permeable pavement, rainwater harvesting, and infiltration practices. All four of these practices were modeled as "infiltration" in WTM but labeled discretely on conceptual plans and summary tables.
5. On "Future Practices" tab, under "Stormwater Retrofit Options"

a. The design storm of 1.95" was selected (WTM rounds to 2") to reflect performance requirements for Bacteria and Shellfish Watershed Protection Area (Section 3.5.2 in *Southern Lowcountry Stormwater Design Manual*)
b. Water Quality Volume was assumed to be 100%
c. Discount Factors: The WTM requires users to input information about the effectiveness and level of implementation of various programs and practices. These discount factors are used to reduce the ideal (literature value) load reductions for a practice that can rarely be achieved. For example, structural practices may have poor maintenance that can reduce effectiveness over time. The WTM provides guidance to select appropriate values. For the May River, we have selected:
    i. Design Factor: applied based on the adequacy of existing design standards (Specific, Legally Binding Standards = 100%)
    ii. Maintenance Factor: based on the type of maintenance conducted on treatment practices (Regular maintenance specified and enforced = 90%)
d. Basic Site Information/assumptions to calculate Water Quality Volume (WQv)
    i. WTM allows the user to either input the area captured/impervious percentage that a given practice treats and it will calculate a Target WQv; or if the practice is sized differently, the user can manually input the WQv Provided. These are the general assumptions with calculating the water quality volumes for each type of recommended BMP in this report:
        1. bioretention target WQv calculated assuming 1 ft ponding, 1.5ft filter media, 1 ft gravel (n =0.4)
        2. infiltration trench target WQv assumed to be 4 ft wide x 4 ft deep x length x porosity (n =0.4)
        3. pervious strip target WQv assumed to be 4 ft wide x 4 ft deep x length x porosity (n =0.4)
        4. infiltration chamber/vault target WQv assumed to be SA x 3ft depth x porosity (0.4)
        5. permeable pavement contributing drainage area assumed to be 2x surface area
        6. irrigation reuse calculated as 1" over athletic fields
        7. conservation area credit calculated according to Section 4.16 in *Southern Lowcountry Stormwater Design Manual*

Table 57 summarizes the pollution load reductions associated with the Full SWRv projects, and Table 58 summarizes the benefits if only the impervious areas were treated (the reduced SWRv amount). The reduced SWRv projects did not include expensive BMPs (such as green roofs and underground infiltration chambers) and reduced the size of other proposed BMPs (such as bioretention and permeable pavement). The figures illustrating each Stormwater BMP Retrofit Project are included in the following sections (5.4.4.1 – 5.4.4.11).

Table 57: WTM Estimates for Potential Benefits of Full Retrofit Projects

Project	Potential SWRv (ft^3)	TN (lbs/yr)	TP (lbs/yr)	TSS (lbs/yr)	Bacteria (billion/yr)	Runoff Reduction (ac-ft/yr)
BELC	29,620.76	97.04	18.37	2,904.84	5,035.91	12.42
BGC	28,784.95	79.15	13.67	2158.08	3547.71	11.17
BH	22,844.32	65.82	11.31	1787.84	2985.28	9.15
BHS	205,705.37	646.87	119.69	18,918.83	32,440.85	86.57
BRC	112,415.53	207.85	32.78	5,179.43	9,123.64	34.80
LCC	57,583.44	158.44	27.15	4,290.37	6,774.20	24.16
MMSBES	136,611.95	424.40	78.79	12,454.48	20,531.34	57.31
MRHS	191,082.46	572.06	100.08	15,819.40	25,510.45	80.10
OHLA	110,767.11	358.98	83.55	9,372.56	15,256.38	46.50
PES	54,711.33	215.04	62.92	3,015.62	5,609.68	22.69
PPT	51,301.38	121.44	17.93	2,833.57	5,271.04	21.32

Table 58: WTM Estimates for Potential Benefits of Reduced Retrofit Projects

Project	Potential SWRv (ft^3)	TN (lbs/yr)	TP (lbs/yr)	TSS (lbs/yr)	Bacteria (billion/yr)	Runoff Reduction (ac-ft/yr)
BELC	19,242.48	66.65	13.34	2,109.71	3,640.14	8.07
BGC	13,051.61	52.28	12.01	1897.49	3164.04	5.51
BH	16,426.31	56.02	15.48	1364.53	2245.89	6.91
BHS	189,363.67	607.71	113.91	18,005.00	30,740.94	79.69
BRC	55,116.42	141.8	23.02	3638.26	6256.74	23.2
LCC	42,005.74	121.22	21.66	3421.84	5158.56	17.62
MMSBES	111,428.11	361.43	69.23	10,941.75	17,759.05	46.75
MRHS	146,410.69	436.73	76.44	12,084.13	19,438.33	61.38
OHLA	81,912.35	267.99	62.94	7,119.78	11,321.50	34.56
PES	47,041.77	186.09	54.71	2592.88	4823.31	19.51
PPT	45,131.95	106.84	15.78	2492.82	4637.16	18.76

The following subsections provide summarized data pertaining to each of the project sites, including the subcatchment (or subcatchments) the project is located in, the amount of impervious area, and the detailed breakdown of WTM estimates of performance for individual BMP types at each site. Note that the project boundary and area was based on the available parcel delineation. Also, the Full SWRv scenario is shown in the corresponding figures for each project and are intended for conceptual sketches for potential locations of structural BMPs; the Reduced SWRv scenario would involve removing or reducing the size of specified BMPs. The figures are provided to give general suggestions for locations of BMPs, but the actual placement and surface areas are subject to a more detailed site investigation including soil testing and location of underground utilities.

5.4.4.1 Bluffton Early Learning Center (BELC)

Subcatchment: SUB-RD-14

HSG: D

Bacteria hotspot subcatchment: No

Subcatchment imperviousness: 23%

Site Area: 7.98 acres

Site impervious area: 2.94 acres

Site imperviousness: 37%

Note: use of "offsite bioretention" refers to MMSBES-3a

Table 59: WTM Summary for Bluffton Early Learning Center Full SWRv Scenario ($916,551.01)

			Annual Practice Effectiveness				
Practice	RR credit	SWRv	TN (lb/yr)	TP (lb/yr)	TSS (lb/yr)	Bacteria (billion/yr)	Runoff Reduction (ac-ft/yr)
filtering trench	0%	-	8.69	3.42	540.51	1,005.46	-
bioretention - standard	60%	7,422.62	22.21	3.71	587.08	1,025.44	3.11
bioretention (offsite)	60%	20,412.22	61.07	10.21	1,614.48	2,819.97	8.56
permeable pavement	30%	685.92	2.44	0.64	101.50	71.07	0.29
rainwater harvesting	100%	1,100.00	2.63	0.39	61.27	113.97	0.46
TOTAL:		29,620.76	97.04	18.37	2,904.84	5,035.91	12.42
SWRv goal		24,784.48					
SWRv remaining		(4,836.28)					

Table 60: WTM Summary for Bluffton Early Learning Center Reduced SWRv Scenario ($649,804.68)

			Annual Practice Effectiveness				
Practice	RR credit	SWRv	TN (lb/yr)	TP (lb/yr)	TSS (lb/yr)	Bacteria (billion/yr)	Runoff Reduction (ac-ft/yr)
filtering trench	0%	-	8.69	3.42	540.51	1,005.46	-
bioretention - standard	60%	7,422.62	22.21	3.71	587.08	1,025.44	3.11
bioretention (offsite)	60%	11,133.94	33.31	5.57	880.62	1,538.17	4.67
permeable pavement	30%	685.92	2.44	0.64	101.50	71.07	0.29
rainwater harvesting	100%						
TOTAL:		19,242.48	66.65	13.34	2,109.71	3,640.14	8.07
SWRv goal		19,250.05					
SWRv remaining		7.57					

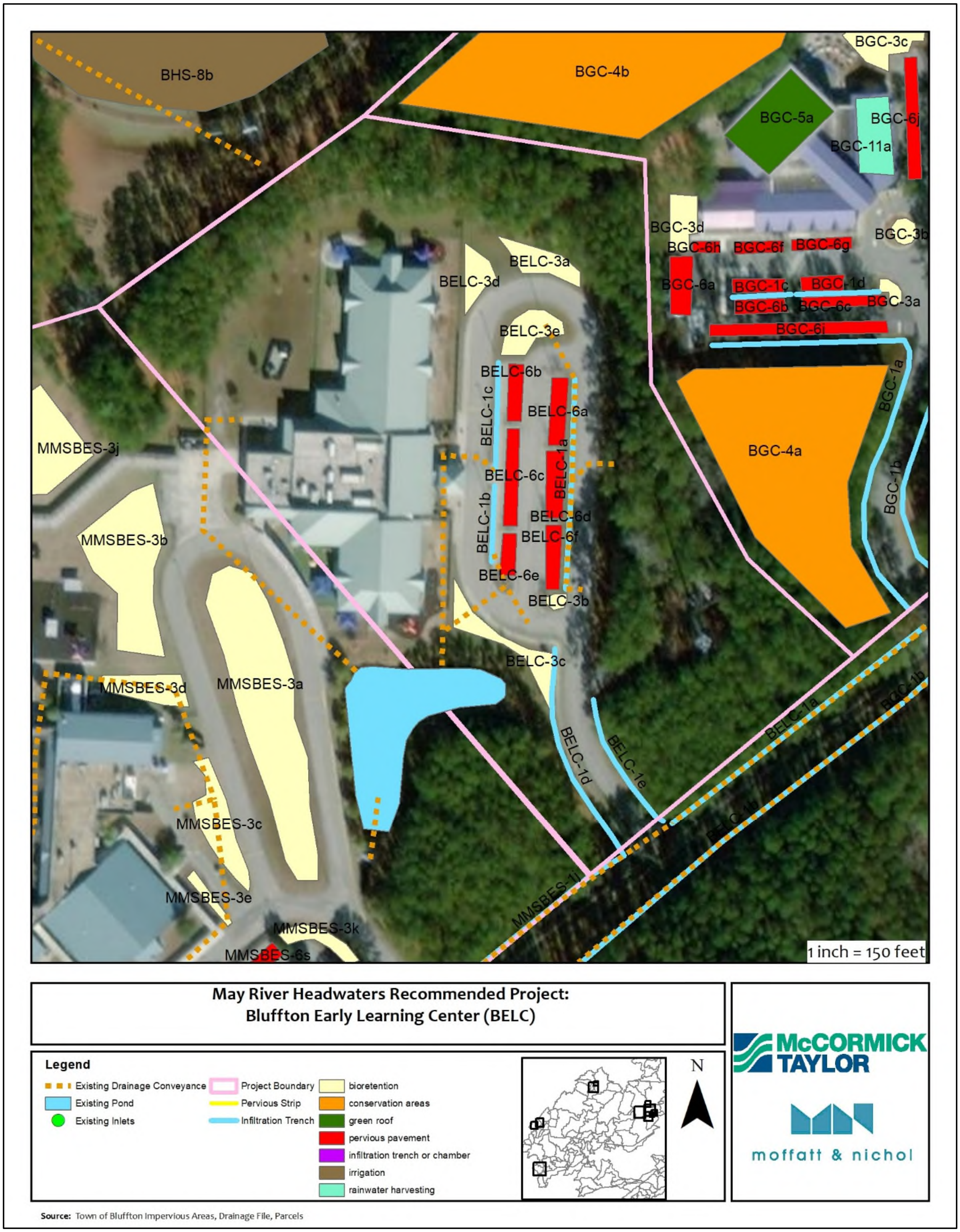

Figure 46. Bluffton Early Learning Center Proposed Stormwater BMP Retrofits

5.4.4.2 Boys and Girls Club of Bluffton (BGC)

Subcatchment: SUB-RD-13 & SUB-RD-14

HSG: D

Bacteria hotspot subcatchment: no

Subcatchment imperviousness: 40% & 23%

Site Area: 11.81 acres

Site impervious area: 3.48 acres

Site imperviousness: 29%

Note: linear bioswale from Full Scenario converted to be part filtering trench in Reduced Scenario to reduce cost

Table 61: WTM Summary for Boys and Girls Club of Bluffton Full SWRv Scenario ($947,830.40)

			Annual Practice Effectiveness				
Practice	**RR credit**	**SWRv**	**TN (lb/yr)**	**TP (lb/yr)**	**TSS (lb/yr)**	**Bacteria (billion/yr)**	**Runoff Reduction (ac-ft/yr)**
bioretention - standard	60%	6,272.63	18.89	3.16	499.33	872.17	2.65
bioswale	60%	16,451.07	49.54	8.29	1309.59	2287.43	6.94
conservation		2,339.53					
green roof	100%	1,008.70	2.42	0.36	56.55	105.19	0.43
permeable pavement	30%	1,513.02	5.42	1.43	225.34	157.78	0.64
rainwater harvesting	100%	1,200.00	2.88	0.43	67.27	125.14	0.51
TOTAL:		28,784.95	79.15	13.67	2158.08	3547.71	11.17
SWRv goal		28,783.17					
SWRv remaining		(1.78)					

Table 62: WTM Summary for Boys and Girls Club of Bluffton Full SWRv Scenario ($718,527.75)

			Annual Practice Effectiveness				
Practice	**RR credit**	**SWRv**	**TN (lb/yr)**	**TP (lb/yr)**	**TSS (lb/yr)**	**Bacteria (billion/yr)**	**Runoff Reduction (ac-ft/yr)**
filtering trench	0%	-	12.11	4.77	753.62	1401.89	0
bioretention - standard	60%	6,272.63	18.89	3.16	499.33	872.17	2.65
bioswale	60%	5,265.96	15.86	2.65	419.2	732.2	2.22
permeable pavement	30%	1,513.02	5.42	1.43	225.34	157.78	0.64
TOTAL:		13,051.61	52.28	12.01	1897.49	3164.04	5.51
SWRv goal		12,874.19					
SWRv remaining		(177.42)					

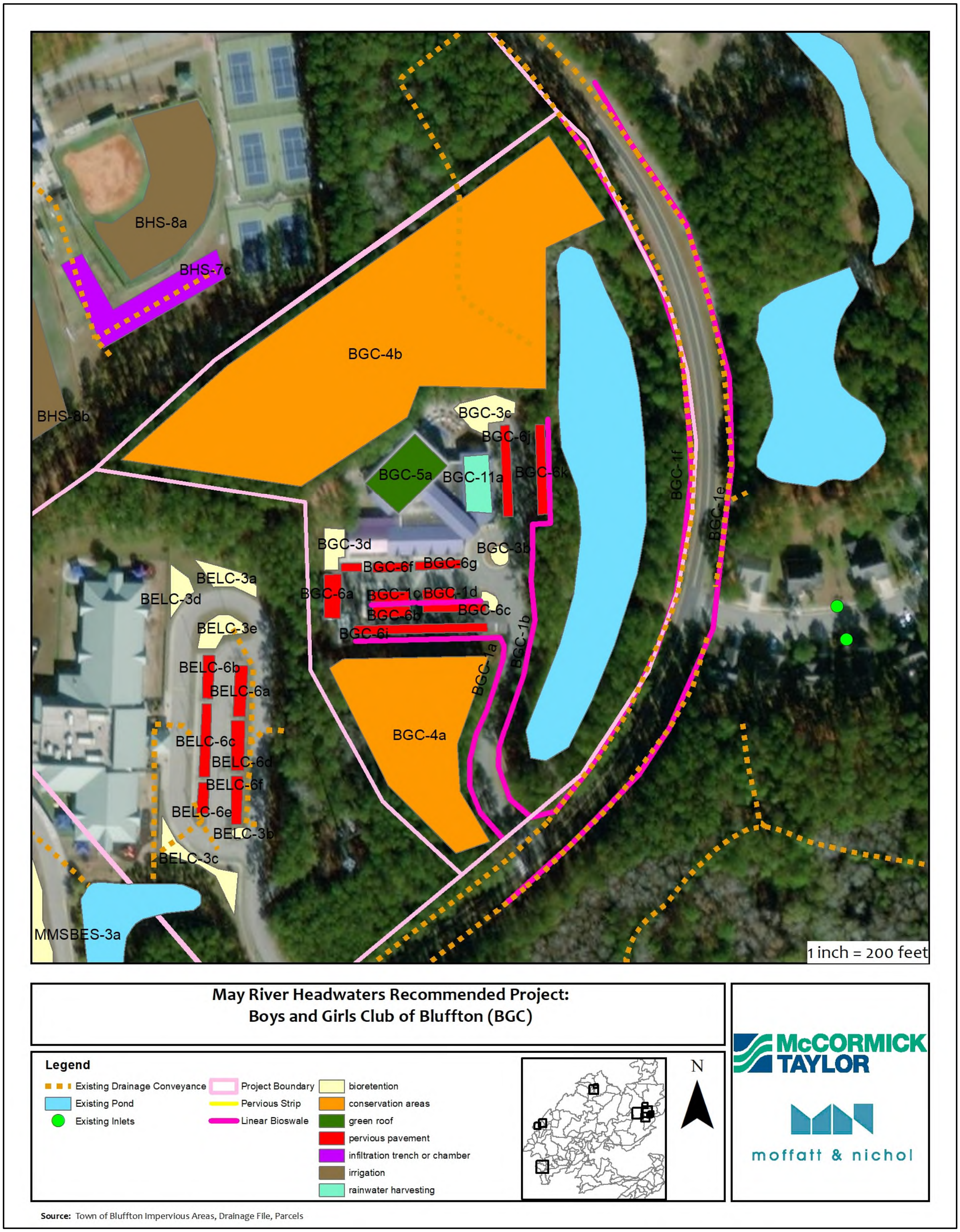

Figure 47. Boys and Girls Club of Bluffton Proposed Stormwater BMP Retrofits

5.4.4.3 Benton House (BH)

Subcatchment: SC105/SC106

HSG: D

Bacteria hotspot subcatchment: yes (SC106)

Subcatchment imperviousness: 16% & 20%

Site Area: 7.11 acres

Site impervious area: 2.85 acres

Site imperviousness: 40%

Note: Pond retrofit to convert existing wet pond to bioretention

Table 63: WTM Summary for Benton House Full SWRv Scenario ($587,355.04)

			Annual Practice Effectiveness				
Practice	RR credit	SWRv	TN (lb/yr)	TP (lb/yr)	TSS (lb/yr)	Bacteria (billion/yr)	Runoff Reduction (ac-ft/yr)
pervious strip	100%	332.44	1.19	0.31	49.35	34.56	0.14
bioretention - standard	60%	6,958.71	20.89	3.49	552.14	964.42	2.93
conservation	100%	1,083.00					
permeable pavement	30%	552.75	1.97	0.52	82.06	57.46	0.23
pond retrofit (0.44 ac)	60%	13,917.42	41.77	6.99	1104.29	1928.84	5.85
TOTAL:		22,844.32	65.82	11.31	1787.84	2985.28	9.15
SWRv goal		22,365.23					
SWRv remaining		(479.09)					

Table 64: WTM Summary for Benton House Reduced SWRv Scenario ($445,750.88)

			Annual Practice Effectiveness				
Practice	RR credit	SWRv	TN (lb/yr)	TP (lb/yr)	TSS (lb/yr)	Bacteria (billion/yr)	Runoff Reduction (ac-ft/yr)
pervious strip	100%	332.44	1.19	0.31	49.35	34.56	0.14
bioretention - standard	60%	6,958.71	20.89	3.49	552.14	964.42	2.93
permeable pavement	30%	552.75	1.97	0.52	82.06	57.46	0.23
pond retrofit (0.44 ac)	60%	8,582.41	31.97	11.16	680.98	1189.45	3.61
TOTAL:		16,426.31	56.02	15.48	1364.53	2245.89	6.91
SWRv goal		16,227.22					
SWRv remaining		(199.09)					

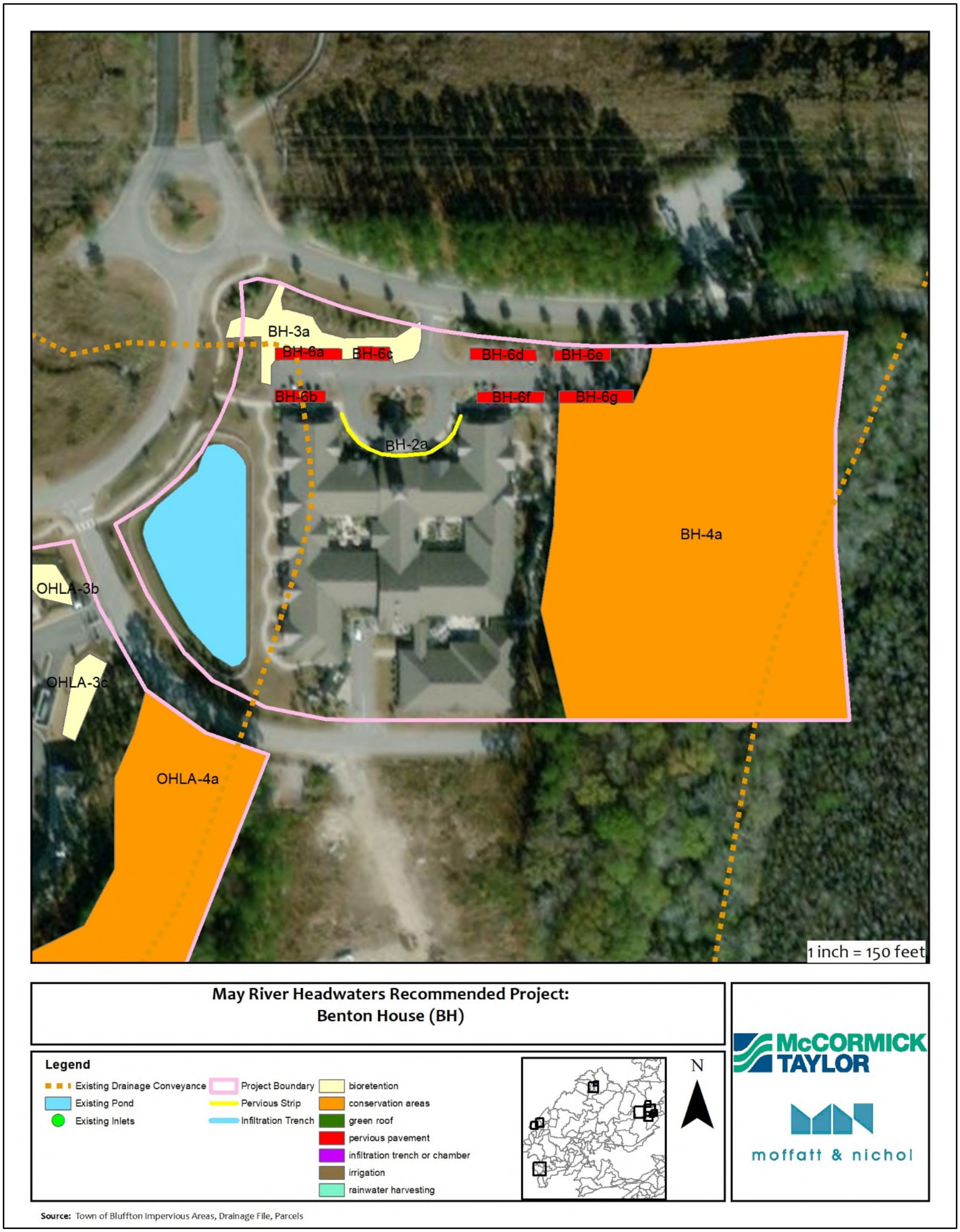

Figure 48. Benton House Proposed Stormwater BMP Retrofits

5.4.4.4 Bluffton High School (BHS)

Subcatchment: SUB-RD-13

HSG: D

Bacteria hotspot subcatchment: no

Subcatchment imperviousness: 40%

Site Area: 54.2 acres

Site impervious area: 27.34 acres

Site imperviousness: 50%

Table 65: WTM Summary for Bluffton High School Full SWRv Scenario ($4,602,142.12)

			Annual Practice Effectiveness				
Practice	**RR credit**	**SWRv**	**TN (lb/yr)**	**TP (lb/yr)**	**TSS (lb/yr)**	**Bacteria (billion/yr)**	**Runoff Reduction (ac-ft/yr)**
filtering trench	0%	-	47.04	18.52	2,927.07	5,444.97	0
bioretention - standard	60%	161,442.07	484.92	81.1	12,819.47	22,391.49	67.94
green roof	100%	4,841.70	11.6	1.71	270.75	503.65	2.04
permeable pavement	30%	7,524.81	26.87	7.07	1,117.88	782.75	3.17
infiltration chamber	100%	11,500.00	27.56	4.07	643.08	1,196.26	4.84
irrigation reuse	100%	20,396.79	48.88	7.22	1,140.58	2,121.73	8.58
TOTAL:		205,705.37	646.87	119.69	18,918.83	32,440.85	86.57
SWRv goal		205,604.01					
SWRv remaining		(101.36)					

Table 66: WTM Summary for Bluffton High School Reduced SWRv Scenario ($4,602,142.12)

			Annual Practice Effectiveness				
Practice	**RR credit**	**SWRv**	**TN (lb/yr)**	**TP (lb/yr)**	**TSS (lb/yr)**	**Bacteria (billion/yr)**	**Runoff Reduction (ac-ft/yr)**
filtering trench	0%	-	47.04	18.52	2,927.07	5,444.97	0
bioretention - standard	60%	161,442.07	484.92	81.1	12,819.47	22,391.49	67.94
permeable pavement	30%	7,524.81	26.87	7.07	1,117.88	782.75	3.17
irrigation reuse	100%	20,396.79	48.88	7.22	1,140.58	2,121.73	8.58
TOTAL:		189,363.67	607.71	113.91	18,005.00	30,740.94	79.69
SWRv goal		176,167.01					
SWRv remaining		(13,196.66)					

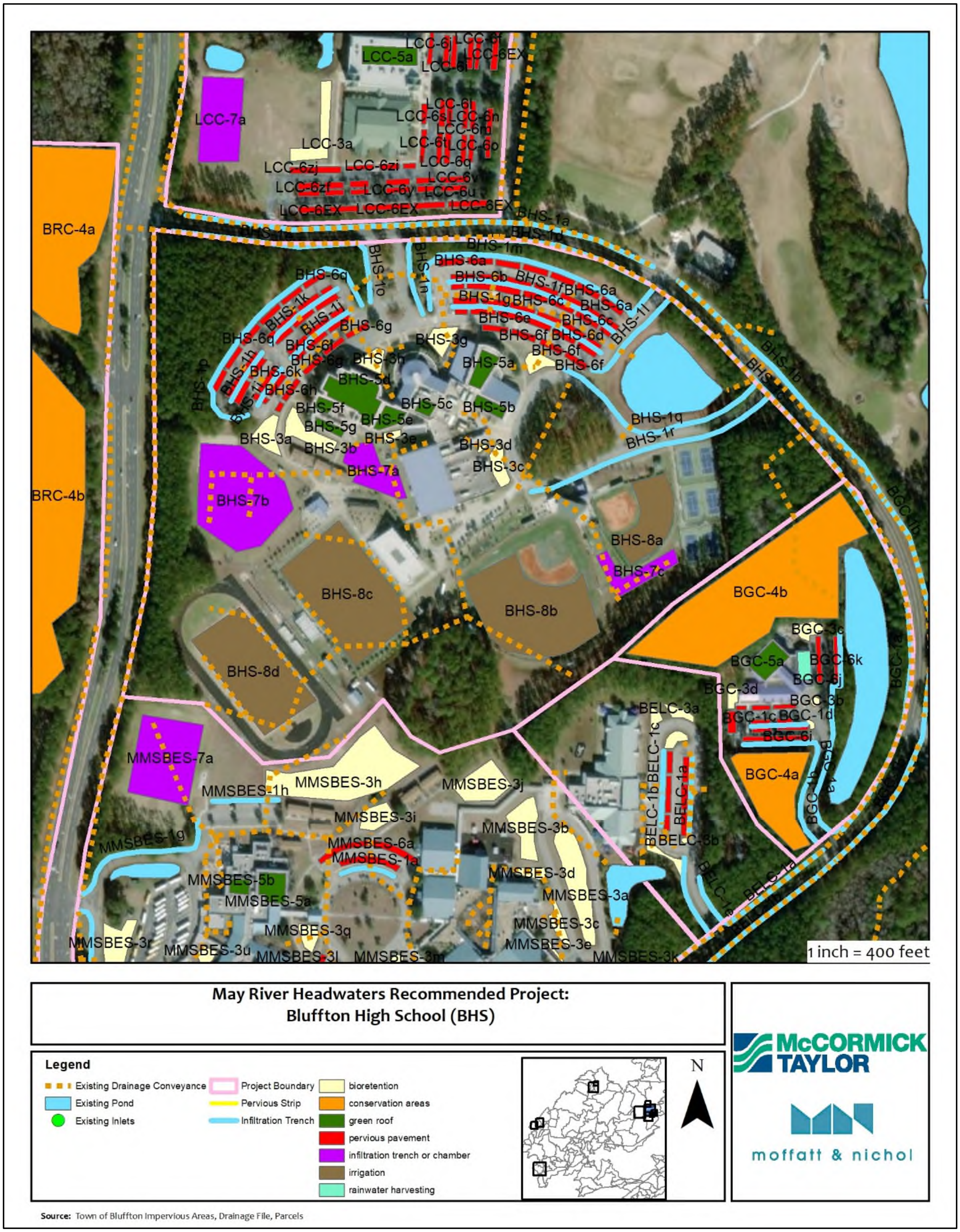

Figure 49. Bluffton High School Proposed Stormwater BMP Retrofits

5.4.4.5 Buckwalter Recreation Center (BRC)

Subcatchment: SUB-RD-8

HSG: D

Bacteria hotspot subcatchment: no

Subcatchment imperviousness: 17%

Site Area: 106.8 acres

Site impervious area: 8.52 acres

Site imperviousness: 8%

Table 67: WTM Summary for Buckwalter Recreation Center Full SWRv Scenario ($4,377,471.99)

			Annual Practice Effectiveness				
Practice	RR credit	SWRv	TN (lb/yr)	TP (lb/yr)	TSS (lb/yr)	Bacteria (billion/yr)	Runoff Reduction (ac-ft/yr)
filtering trench	0%	-	2.44	0.96	151.65	282.1	0
bioretention - standard	60%	6,958.71	20.9	3.5	552.56	965.15	2.93
conservation		29,738.81					
green roof	100%	1,815.60	4.35	0.64	101.53	188.87	0.76
permeable pavement	30%	2,602.41	9.29	2.45	386.61	270.71	1.1
infiltration chamber	100%	69,500.00	166.56	24.59	3886.42	7229.57	29.25
rainwater harvesting	100%	1,800.00	4.31	0.64	100.66	187.24	0.76
TOTAL:		112,415.53	207.85	32.78	5,179.43	9,123.64	34.80
SWRv goal		112,313.34					
SWRv remaining		(102.19)					

Table 68: WTM Summary for Buckwalter Recreation Center Reduced SWRv Scenario ($2,694,173.79)

			Annual Practice Effectiveness				
Practice	RR credit	SWRv	TN (lb/yr)	TP (lb/yr)	TSS (lb/yr)	Bacteria (billion/yr)	Runoff Reduction (ac-ft/yr)
filtering trench	0%	-	2.44	0.96	151.65	282.1	0
bioretention - standard	60%	6,958.71	20.9	3.5	552.56	965.15	2.93
permeable pavement	30%	2,602.41	9.29	2.45	386.61	270.71	1.1
infiltration chamber	100%	43,000.00	103.05	15.21	2404.55	4472.97	18.09
rainwater harvesting	100%	2,555.30	6.12	0.9	142.89	265.81	1.08
TOTAL:		55,116.42	141.8	23.02	3638.26	6256.74	23.2
SWRv goal		54,820.41					
SWRv remaining		(296.01)					

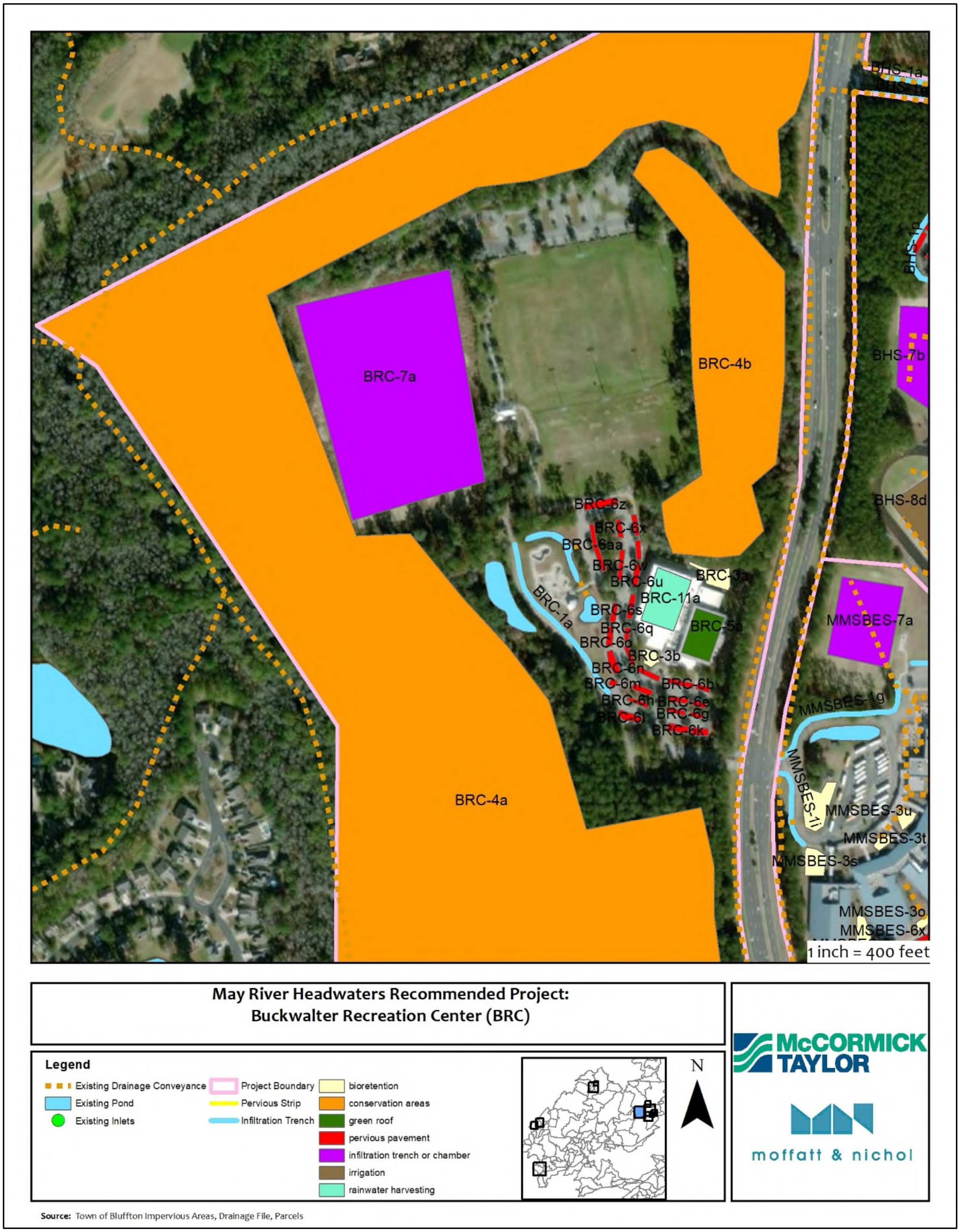

Figure 50. Buckwalter Recreation Center Proposed Stormwater BMP Retrofits

5.4.4.6 Lowcountry Community Church (LCC)

Subcatchment: SUB-RD-6

HSG: D

Bacteria hotspot subcatchment: no

Subcatchment imperviousness: 24%

Site Area: 16.25 acres

Site impervious area: 6.39 acres

Site imperviousness: 39%

Note: site already has some existing pervious parking spaces

Table 69: WTM Summary for Lowcountry Community Church Full SWRv Scenario ($2,773,224.00)

			Annual Practice Effectiveness				
Practice	**RR credit**	**SWRv**	**TN (lb/yr)**	**TP (lb/yr)**	**TSS (lb/yr)**	**Bacteria (billion/yr)**	**Runoff Reduction (ac-ft/yr)**
bioretention - standard	60%	23,195.70	69.47	11.62	1836.44	3207.67	9.73
green roof	100%	1,277.70	3.05	0.45	71.24	132.51	0.54
permeable pavement	30%	1,492.86	5.32	1.4	221.12	154.83	0.63
ex. permeable pvmnt	30%	4,317.18	15.37	4.05	639.47	447.76	1.81
infiltration chamber	100%	27,300.00	65.23	9.63	1522.1	2831.43	11.45
TOTAL:		57,583.44	158.44	27.15	4290.37	6774.2	24.16
SWRv goal		57,578.35					
SWRv remaining		(5.09)					

Table 70: WTM Summary for Lowcountry Community Church Reduced SWRv Scenario ($1,797,828.48)

			Annual Practice Effectiveness				
Practice	**RR credit**	**SWRv**	**TN (lb/yr)**	**TP (lb/yr)**	**TSS (lb/yr)**	**Bacteria (billion/yr)**	**Runoff Reduction (ac-ft/yr)**
bioretention - standard	60%	23,195.70	69.47	11.62	1836.44	3207.67	9.73
permeable pavement	30%	1,492.86	5.32	1.4	221.12	154.83	0.63
ex. permeable pvmnt	30%	4,317.18	15.37	4.05	639.47	447.76	1.81
infiltration chamber	100%	13,000.00	31.06	4.59	724.81	1348.3	5.45
TOTAL:		42,005.74	121.22	21.66	3421.84	5158.56	17.62
SWRv goal		41,261.68					
SWRv remaining		(744.06)					

Figure 51. Lowcountry Community Church Proposed Stormwater BMP Retrofits

5.4.4.7 McCracken Middle School/Bluffton Elementary School (MMSBES)

Subcatchment: SUB-RD-8, 13, 14, 15

HSG: D

Bacteria hotspot subcatchment: no

Subcatchment imperviousness: 17, 40, 23, 25%

Site Area: 41.31 acres

Site impervious area: 17.85 acres

Site imperviousness: 43%

Table 71: WTM Summary for McCracken Middle School/Bluffton Elementary School Full SWRv Scenario ($7,033,323.84)

			Annual Practice Effectiveness				
Practice	**RR credit**	**SWRv**	**TN (lb/yr)**	**TP (lb/yr)**	**TSS (lb/yr)**	**Bacteria (billion/yr)**	**Runoff Reduction (ac-ft/yr)**
filtering trench	0%	-	24.49	9.64	1523.68	2834.37	0
bioretention - standard	60%	102,061.08	305.65	51.12	8,080.23	14,113.56	42.82
green roof	100%	1,344.90	3.21	0.47	74.98	139.49	0.56
permeable pavement	30%	10,006.17	35.62	9.38	1482.11	1037.78	4.2
infiltration chamber	100%	23,199.80	55.43	8.18	1293.48	2406.14	9.73
TOTAL:		136,611.95	424.40	78.79	12,454.48	20,531.34	57.31
SWRv goal		134,181.89					
SWRv remaining		(2,430.06)					

Table 72: WTM Summary for McCracken Middle School/Bluffton Elementary School Reduced SWRv Scenario ($4,338,876.48)

			Annual Practice Effectiveness				
Practice	**RR credit**	**SWRv**	**TN (lb/yr)**	**TP (lb/yr)**	**TSS (lb/yr)**	**Bacteria (billion/yr)**	**Runoff Reduction (ac-ft/yr)**
filtering trench	0%	-	24.49	9.64	1523.68	2834.37	0
bioretention - standard	60%	97,421.94	291.76	48.80	7,712.94	13,472.04	40.87
permeable pavement	30%	10,006.17	35.62	9.38	1482.11	1037.78	4.2
infiltration chamber	100%	4,000.00	9.56	1.41	223.02	414.86	1.68
TOTAL:		111,428.11	361.43	69.23	10,941.75	17,759.05	46.75
SWRv goal		110,627.54					
SWRv remaining		(800.57)					

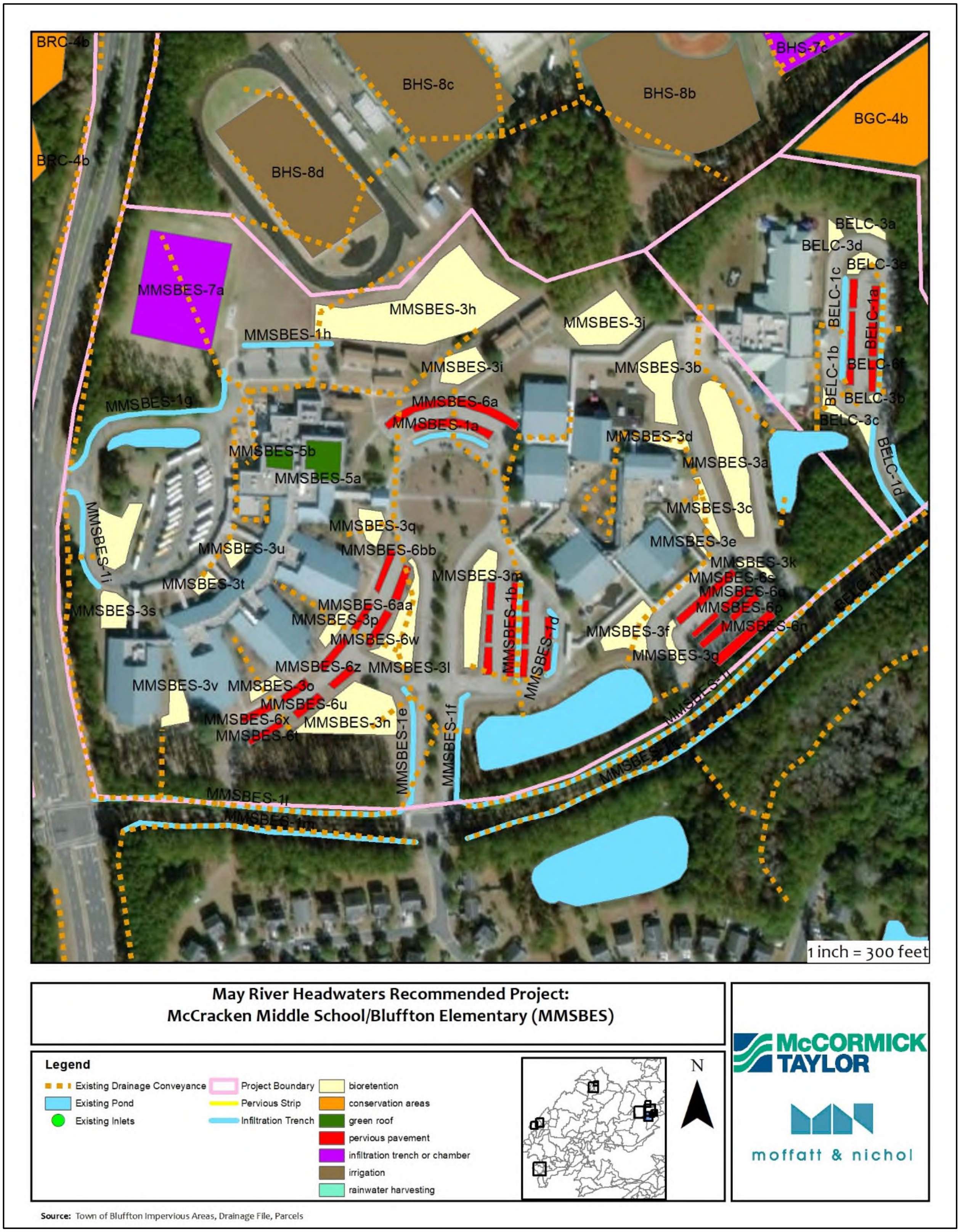

Figure 52. McCracken Middle School/Bluffton Elementary School Proposed Stormwater BMP Retrofits

5.4.4.8 May River High School (MRHS)

Subcatchment: SC142

HSG: D

Bacteria hotspot subcatchment: yes

Subcatchment imperviousness: 39%

Site Area: 59.0 acres

Site impervious area: 23.1 acres

Site imperviousness: 39%

Table 73: WTM Summary for May River High School Full SWRv Scenario ($4,891,503.46)

			Annual Practice Effectiveness				
Practice	RR credit	SWRv	TN (lb/yr)	TP (lb/yr)	TSS (lb/yr)	Bacteria (billion/yr)	Runoff Reduction (ac-ft/yr)
filtering trench	0%	-	0.84	0.33	52.46	97.59	-
pervious strip	100%	14,319.51	50.94	13.41	2,119.46	1,484.06	6.00
bioretention - standard	60%	162,369.90	485.91	81.27	12,845.59	22,437.12	68.07
irrigation reuse	100%	14,393.05	34.37	5.07	801.89	1,491.68	6.03
TOTAL:		191,082.46	572.06	100.08	15,819.40	25,510.45	80.10
SWRv goal		189,783.00					
SWRv remaining		(1,299.46)					

Table 74: WTM Summary for May River High School Reduced SWRv Scenario ($3,729,151.15)

			Annual Practice Effectiveness				
Practice	RR credit	SWRv	TN (lb/yr)	TP (lb/yr)	TSS (lb/yr)	Bacteria (billion/yr)	Runoff Reduction (ac-ft/yr)
filtering trench	0%	-	0.84	0.33	52.46	97.59	-
pervious strip	100%	11,400.00	40.56	10.67	1,687.34	1,181.48	4.78
bioretention - standard	60%	120,617.64	360.96	60.37	9,542.44	16,667.58	50.57
irrigation reuse	100%	14,393.05	34.37	5.07	801.89	1,491.68	6.03
TOTAL:		146,410.69	436.73	76.44	12,084.13	19,438.33	61.38
SWRv goal		146,295.27					
SWRv remaining		(115.42)					

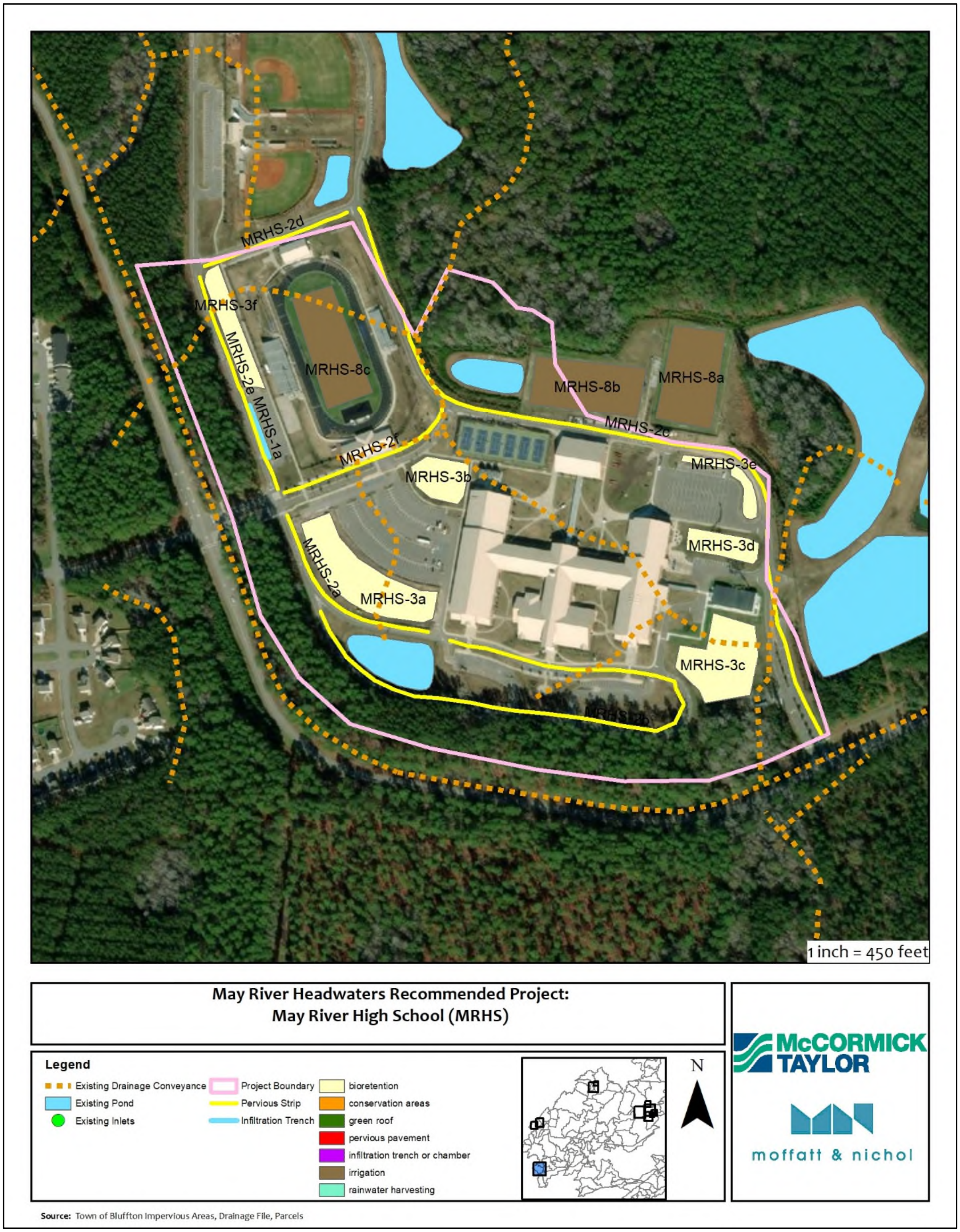

Figure 53. May River High School Bluffton Elementary School Proposed Stormwater BMP Retrofits

5.4.4.9 One Hampton Lake Apartments (OHLA)

Subcatchment: SC106/108

HSG: D

Bacteria hotspot subcatchment: yes

Subcatchment imperviousness: 20/50%

Site Area: 29.55 acres

Site impervious area: 12.19 acres

Site imperviousness: 41%

Table 75: WTM Summary for One Hampton Lakes Apartments Full SWRv Scenario ($3,339,004.19)

			Annual Practice Effectiveness				
Practice	RR credit	SWRv	TN (lb/yr)	TP (lb/yr)	TSS (lb/yr)	Bacteria (billion/yr)	Runoff Reduction (ac-ft/yr)
filtering trench	0%	-	1.99	1.69	98.29	182.83	-
bioretention - standard	60%	102,988.91	331.14	75.05	8,198.63	14,320.38	43.45
conservation		556.00					
permeable pavement	30%	7,222.20	25.85	6.81	1,075.64	753.17	3.05
TOTAL:		110,767.11	358.98	83.55	9,372.56	15,256.38	46.50
SWRv goal		110,469.23					
SWRv remaining		(297.88)					

Table 76: WTM Summary for One Hampton Lakes Apartments Reduced SWRv Scenario ($2,738,800.35)

			Annual Practice Effectiveness				
Practice	RR credit	SWRv	TN (lb/yr)	TP (lb/yr)	TSS (lb/yr)	Bacteria (billion/yr)	Runoff Reduction (ac-ft/yr)
filtering trench	0%	-	1.99	1.69	98.29	182.83	-
bioretention - standard	60%	74,690.15	240.15	54.44	5,945.85	10,385.50	31.51
permeable pavement	30%	7,222.20	25.85	6.81	1,075.64	753.17	3.05
TOTAL:		81,912.35	267.99	62.94	7,119.78	11,321.50	34.56
SWRv goal		81,799.21					
SWRv remaining		(113.14)					

Figure 54. One Hampton Lake Apartments Proposed Stormwater BMP Retrofits

5.4.4.10 Pritchardville Elementary School (PES)

Subcatchment: SC111

HSG: A

Bacteria hotspot subcatchment: no

Subcatchment imperviousness: 28%

Site Area: 24.53 acres

Site impervious area: 7.51 acres

Site imperviousness: 31%

Table 77: WTM Summary for Pritchardville Elementary School Full SWRv Scenario ($2,249,108.30)

			Annual Practice Effectiveness				
Practice	**RR credit**	**SWRv**	**TN (lb/yr)**	**TP (lb/yr)**	**TSS (lb/yr)**	**Bacteria (billion/yr)**	**Runoff Reduction (ac-ft/yr)**
filtering trench	100%	6,377.30	25.23	7.42	351.51	653.88	2.65
bioretention - standard	100%	9,381.04	37.11	10.91	517.07	961.86	3.89
green roof	100%	874.20	2.07	0.3	48.18	89.63	0.36
permeable pavement	100%	4,102.00	16.23	4.77	226.1	420.59	1.7
infiltration chamber	100%	33,976.80	134.40	39.52	1,872.76	3,483.72	14.09
TOTAL:		54,711.33	215.04	62.92	3,015.62	5,609.68	22.69
SWRv goal		54,193.35					
SWRv remaining		(517.98)					

Table 78: WTM Summary for Pritchardville Elementary School Reduced SWRv Scenario ($1,719,070.22)

			Annual Practice Effectiveness				
Practice	**RR credit**	**SWRv**	**TN (lb/yr)**	**TP (lb/yr)**	**TSS (lb/yr)**	**Bacteria (billion/yr)**	**Runoff Reduction (ac-ft/yr)**
filtering trench	100%	6,377.30	25.23	7.42	351.51	653.88	2.65
bioretention - standard	100%	9,381.04	37.11	10.91	517.07	961.86	3.89
permeable pavement	100%	4,102.00	16.23	4.77	226.1	420.59	1.7
infiltration chamber	100%	27,181.44	107.52	31.61	1498.2	2786.98	11.27
TOTAL:		47,041.77	186.09	54.71	2592.88	4823.31	19.51
SWRv goal		46,549.45					
SWRv remaining		(492.32)					

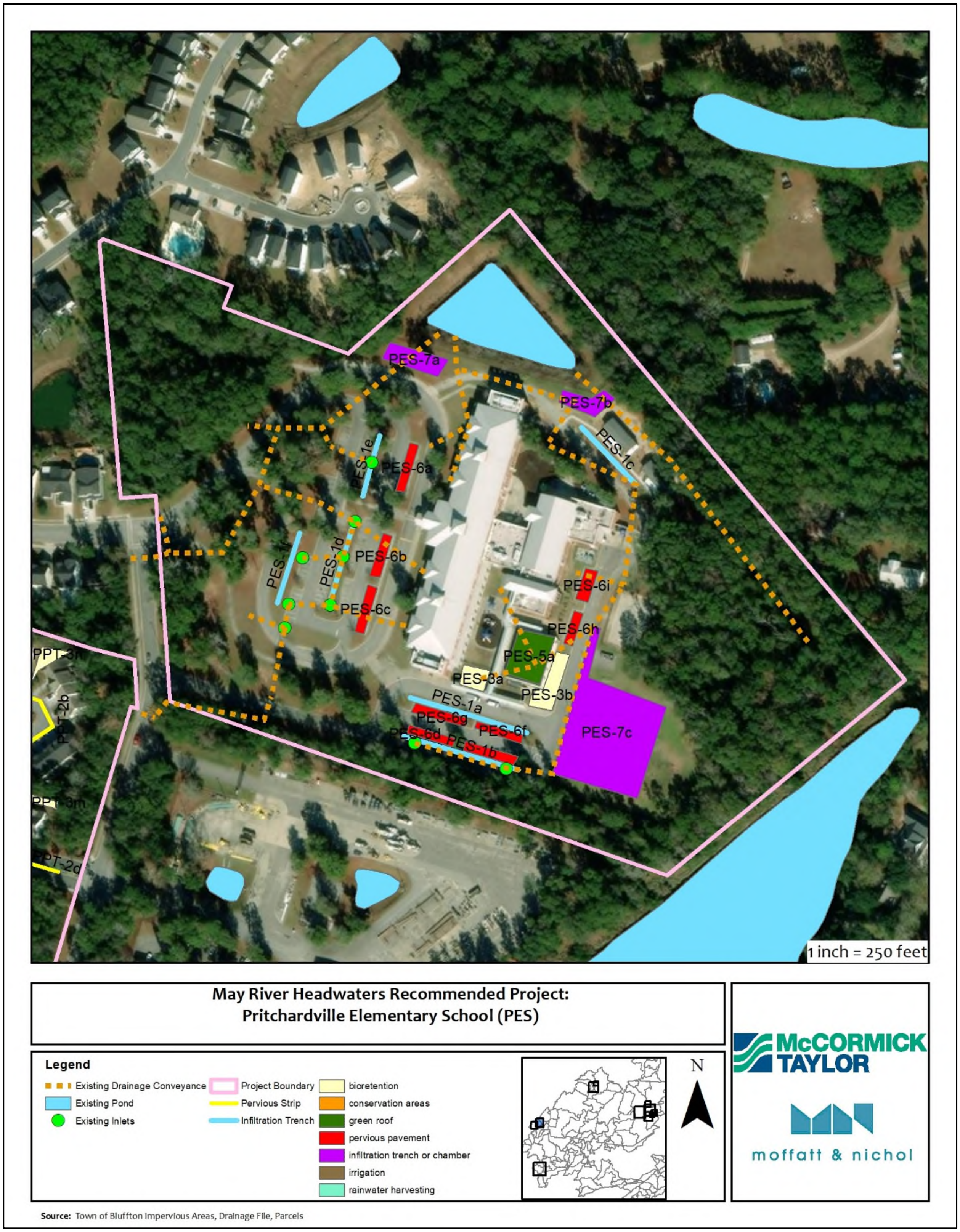

Figure 55. Pritchardville Elementary School Proposed Stormwater BMP Retrofits

5.4.4.11 Palmetto Pointe Townhomes (PPT)

Subcatchment: SC111

HSG: A

Bacteria hotspot subcatchment: no

Subcatchment imperviousness: 28%

Site Area: 18.53 acres

Site impervious area: 7.21 acres

Site imperviousness: 39%

Note: rainwater harvesting assumed 50 gallon rain barrels at 113 homes

Table 79: WTM Summary for Palmetto Pointe Townes Full SWRv Scenario ($933,991.48)

			Annual Practice Effectiveness				
Practice	**RR credit**	**SWRv**	**TN (lb/yr)**	**TP (lb/yr)**	**TSS (lb/yr)**	**Bacteria (billion/yr)**	**Runoff Reduction (ac-ft/yr)**
pervious strip	100%	9,060.48	21.45	3.17	500.45	930.93	3.77
bioretention - standard	100%	38,659.50	91.51	13.51	2,135.31	3,972.14	16.07
permeable pavement	100%	2,824.30	6.69	0.99	156	290.19	1.17
rainwater harvesting	100%	757.10	1.79	0.26	41.81	77.78	0.31
TOTAL:		51,301.38	121.44	17.93	2,833.57	5,271.04	21.32
SWRv goal		51,069.96					
SWRv remaining		(231.42)					

Table 80: WTM Summary for Palmetto Pointe Townes Reduced SWRv Scenario ($827,834.40)

			Annual Practice Effectiveness				
Practice	**RR credit**	**SWRv**	**TN (lb/yr)**	**TP (lb/yr)**	**TSS (lb/yr)**	**Bacteria (billion/yr)**	**Runoff Reduction (ac-ft/yr)**
pervious strip	100%	9,060.48	21.45	3.17	500.45	930.93	3.77
bioretention - standard	100%	33,247.17	78.7	11.62	1836.37	3416.04	13.82
permeable pavement	100%	2,824.30	6.69	0.99	156	290.19	1.17
TOTAL:		45,131.95	106.84	15.78	2492.82	4637.16	18.76
SWRv goal		44,852.92					
SWRv remaining		(279.03)					

Figure 56. Palmetto Pointe Townes Proposed Stormwater BMP Retrofits

5.4.5 Ranking and Prioritization of Stormwater BMP Retrofit Projects

In order to narrow down the extensive list of potential restoration projects to highlight priorities for the May River Headwaters watersheds, an evaluation matrix was developed (Table 68). Each project was scored with respect to feasibility for cost (20 points), location within a subcatchment flagged as a bacteria hotspot (10), subcatchment imperviousness (10), potential bacteria load reduction (20), potential runoff reduction (15), maintenance requirements (15), potential for agreeable partnerships with landowners (10), amount of effort required for permitting (15), how well the surrounding community will respond to the project's installation (10), and ease of access to the site for both construction and maintenance (10). Projects located in subcatchments that have the highest bacteria loadings, received an additional ten (10) points due to their importance to the overall improvement to the May River.

Impervious area (for subwatersheds, subcatchments, and project sites) was calculated according using the current Town of Bluffton records for impervious surfaces, which include building footprints, roadways, sidewalks, and parking lots, as well as the footprint of non-infiltrating stormwater BMPs or their permanent pool (e.g. stormwater ponds and lagoons). This definition of impervious area is also consistent with the new *Southern Lowcountry Post Construction Stormwater Ordinance and Design Manual.*

The cost metric is based on the potential water quality volume possible per BMP type at each site divided by the total cost of the BMP type projects located on each site. The total cost includes the Town's project management, designer fee, construction, and a 20% contingency to account for unknowns at this time, as summarized in Table 80 below. The water quality volume possible is based upon the conceptual footprint of the BMP with assumed BMP design criteria. This cost per acre-ft treated normalizes the projects for appropriate ranking.

Table 81: Unit Cost Estimates for BMPs

Project Type	Unit	Cost
Bioretention	Acre	$987,264.00
Conservation Area	Acre	Variable
Green Roof	Acre	$1,568,160.00
Permeable Pavement	Acre	$627,264.00
Infiltration Chamber	Acre	$2,509,056.00
Irrigation Reuse	Acre	$8,640.00
Rainwater Harvesting	Cubic Foot Stored	$14.40
Infiltration/Filtering Trench	Linear Foot	$97.92
Pervious Pavement Strip	Linear Foot	$187.20

It is important to view these stormwater retrofit projects as a flexible framework for selecting potential projects; the final design will be contingent upon a more formal analysis of site conditions. For example, the ability to achieve runoff reduction through infiltration practices was considered based on NRCS mapping (hydrologic soil groups A and B were assumed to permit infiltration, whereas C and D may require an underdrain). Alternative methods such as green roofs and rainwater harvesting should be considered as a feasible option to achieve runoff reduction in these poorly drained soils. It should be noted that the scoring was erred on the conservative side when considering infiltration potential. It is imperative that site specific infiltration tests be completed to see if runoff reduction potential scoring can be increased. An actual geotechnical survey, including an infiltration test, will be required to finalize the conceptual plans. For example, it may be possible to install bioretention or pervious pavement with an enhanced design that allows for more infiltration in HSG C and D locations. In addition to achieving a greater reduction of bacteria, the ability for infiltration will also allow for a smaller BMP footprint, which would further reduce the total cost of the project. Conversely, a survey on site may reveal underground utilities or other conflicts that would reduce the available space for proposed BMPs.

Table 82: Project Evaluation and Ranking Criteria

Metric	Total Score	Potential Points Awarded					
Cost	20	> $10 mil = 1	$5 mil – < $10 mil = 5	$1 mil – <5 mil = 10	$500k – < $1 mil = 15	<$500k = 20	
Located in Bacteria Hotspot Subcatchment	10	Top 10 FC load = 10					
Subcatchment Imperviousness	10	> 30% = 10	20-30% = 8	10-20% = 4	< 10% = 0		
Bacteria Load Reduction (billion FC/year)	20	<1,000 = 5	1,000 to 4,999 = 10	5,000 to 9,999 = 15	>10,000 = 20		
Runoff Reduction	15	> 1,000 ac-ft = 15	500 – 1000 ac-ft = 10	< 500 ac-ft = 5			
Maintenance Burden	15	BI = 15	AN = 12	IL = 8	DALS = 4		
Landowner Cooperation	10	PUB, MIN = 10	PUB, MAJ = 8	ROAD = 5	PRIV, MIN = 4	PUB, MAJ = 2	PRIV, MAJ = 0
Permitting Burden	15	NP = 15	TP = 13	T+E = 10	T+B = 8	EIP = 5	
Acceptance/Visibility	10	HI, PUB = 10	HI, PRIV = 8	LOW = 6	HI, CI = 5		
Accessibility	10	NAI = 10	MAI = 8	MULT = 4	MJAI = 1		
TOTAL	**135**						
Notes:		*BI = minimal biannual maintenance* *AN = minimal annual maintenance* *IL = intensive landscaping* *DALS = difficult access, intensive landscaping* *PUB = public owned property* *MIN = minimal impact on property* *ROAD = within roadway adjoining private property* *PRIV = privately owned property* *MAJ = major impact on property* *NP = no permits*			*TP = typical permits* *T+E = typical plus environmental permits* *T+B = typical plus building permits* *EIP = environmental impacts permitting* *HI = high visibility* *LOW = low visibility* *CI = conflict of interest/goals* *NAI = no access impediments (ROW)* *MAI = minor access impediments* *MULT = multiple private access points* *MJAI = major access impediments*		

Utilizing the project evaluation and ranking matrix information, the eleven (11) stormwater retrofit projects were scored as described in Table 82. Keep in mind that the proposed BMPs are different for each project site (for example, while every project has bioretention, only about half have green roofs or conservation areas). Interestingly, the two projects (PES and PPT) that had the assumption of well-drained soils (HSG A or B) were not the top-ranked projects. This may be due to the presence of two relatively expensive/low priority BMP types at PES (infiltration chamber and green roof for the Full SWRv scenario), and the lower ranking associated with private property (such as PPT).

Table 83: Stormwater Retrofit Project Rankings by Location

FULL SWRv			REDUCED SWRv		
Location	Score[1]	Total Cost	Location	Score[1]	Total Cost
MRHS	96.5	$4,891,503.46	MRHS	96.5	$3,729,151.15
OHLA	88.5	$3,339,004.19	BGC	93.7	$649,804.68
BGC	85	$947,830.40	BHS	90.3	$2,905,392.99
BELC	82	$916,551.28	OHLA	88.0	$2,738,800.40
BHS	78.8	$4,602,142.11	MMBES	84.0	$4,338,876.48
BH	77.8	$587,355.04	BELC	81.7	$649,804.68
PPT	76.8	$933,991.48	BRC	77.2	$2,694,173.79
MMBES	75.6	$7,033,323.84	PES	77.0	$1,719,070.22
BRC	72.7	$4,377,471.68	BH	76.0	$445,750.88
PES	68.6	$2,249,108.30	PPT	72.3	$827,834.40
LCC	61.8	$2,773,224.00	LCC	71.3	$1,797,828.48
[1]Score is the average score of all projects recommended for each location (e.g. bioretention, rainwater harvesting, pervious strip, and permeable pavement)					

Table 84 ranks the average scores for the different BMP types across all project sites. Irrigation reuse and conservation areas ranked the highest with infiltration chambers and green roofs ranking lowest overall. The two projects that included irrigation reuse were high schools with athletic fields that were assumed to 1) require irrigation and 2) have the capacity/infrastructure to allow for it to be installed. The four projects with the potential for conservation areas were BGC, BH, BRC, and OHLA. One of the assumptions for CPA projects was that the typical cost of easements would be between $5,000 - $20,000 depending on the size of the tract and how much the land trust will require for the stewardship fee; for the purpose of this evaluation, the lower end of fee was assumed. The ranking of bioretention near the middle of the projects reflects that the majority of the BMPs were specified with an underdrain, so there was a reduced potential for bacteria load reduction. Furthermore, the landscaping costs associated with bioretention have the potential to make it a more expensive BMP than a simple rainwater harvesting cistern. Because these stormwater retrofit projects would involve modifying existing impervious surfaces, both permeable pavement and pervious strips would require removing and replacing asphalt (an additional cost) and installing an underdrain (assuming limited infiltration potential and thus reduced bacteria removal efficiency). Green roofs scored lowest, due to cost; however, they should still be considered in areas with large building footprints and/or poorly drained soils where in-ground BMPs are not as feasible. There are additional benefits to green roofs (such as prolonged roof life and building energy savings) that are not accounted for in the ranking matrix in Table 82.

Table 84: BMP Type Rankings

FULL SWRv			REDUCED SWRv		
Type	Avg. Score[1]	Count[2]	Type	Avg. Score	Count
IRRIGATION REUSE	95.0	2	IRRIGATION REUSE	95	2
CONSERVATION AREA	90.8	4	RAINWATER HARVESTING	94	1
FILTERING TRENCH	89.2	6	FILTERING TRENCH	91	7
RAINWATER HARVESTING	88.0	4	BIORETENTION	86	11
BIORETENTION	86.3	11	INFILTRATION TRENCH	84	1
INFILTRATION TRENCH	84.0	1	PERVIOUS STRIP	79	3
PERVIOUS STRIP	78.7	3	PERMEABLE PAVEMENT	76	10
PERMEABLE PAVEMENT	76.3	10	INFILTRATION CHAMBER	70	4
INFILTRATION CHAMBER	73.8	5	CONSERVATION AREA		0
GREEN ROOF	36.7	6	GREEN ROOF		0

[1]Average score was calculated from the total scores for each project type (e.g. bioretention) divided by the count (number of project locations with that project type).

[2]Count: number of project locations with that project type. Note that project locations may have multiple suggested locations for a specific individual project type. For example, a school may have 5 different areas identified for bioretention; however, that only counts as 1 project type (bioretention).

Table 85: Cost and Ranking of Proposed Stormwater Retrofit BMPs (Full SWRv) by Project ID and Type

Project ID	Project Type	Subcatchment	Cost (Project Management, Design, Construction)	Target WQv (CFT)	Cost per WQv AC-CFT Treated	Cost Score	Located in Hotspot Sub Catchment (Yes / No)	Hot Spot Score	Subcatchment Percent Impervious	Subcatchment Percent Impervious Score	Bacteria Load Reduction (billion/yr)	Load Reduction Score	Maintenance Burden	Maintenance Burden Score	landowner Cooperation	landowner Cooperation Score	Permitting Burden	Permitting Burden Score	Acceptance/Visibility	Acceptance/Visibility Score	Accessibility	Accessibility Score	Total Score
BELC	FILTERING TRENCH	RD-14	$185,590	12,130	$666,472	15	NO	0	23	8	1,005.46	10	BI	15	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	89
BELC	BIORETENTION	RD-14	$608,486	46,391	$571,349	15	NO	0	23	8	3,845.41	10	IL	8	PUB.MAJ	8	TP	13	HI/PUB	10	MAI	8	80
BELC	RAINWATER HARVESTING	RD-14	$15,840	1,100	$627,264	15	NO	0	23	8	113.97	5	AN	12	PUB/MIN	10	NP	15	HI/PUB	10	MAI	8	83
BELC	PERMEABLE PAVEMENT	RD-14	$106,635	2,286	$2,031,585	10	NO	0	23	8	71.07	5	AN	12	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	76
BGC	PERMEABLE PAVEMENT	RD-13, 14	$194,452	5,043	$1,679,486	10	YES	10	40/23	10	157.78	5	AN	12	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	88
BGC	BIORETENTION	RD-13, 14	$501,155	37,873	$576,410	15	YES	10	40/23	10	872.17	5	IL	8	PUB.MAJ	8	TP	13	HI/PUB	10	MAI	8	87
BGC	RAINWATER HARVESTING	RD-13, 14	$12,000	1,200	$435,600	20	YES	10	40/23	10	49.09	5	AN	12	PUB/MIN	10	NP	15	HI/PUB	10	MAI	8	100
BGC	CONSERVATION AREA	RD-13, 14	$5,000	2,340	$93,096	20	YES	10	40/23	10		5	BI	15	PUB/MAJ	8	NP	15	HI/PUB	10	NAI	10	103
BGC	GREEN ROOF	RD-13, 14	$235,224	1,009	$10,157,983	1	YES	10	40/23	10	105.19	5	DALS	4	PUB/MAJ	2	T+B	8	LOW	6	MJAI	1	47
BH	BIORETENTION	SC105,106	$462,125	34,794	$578,560	15	YES	10	16/23	8	964.42	5	IL	8	PRIV/MAJ	0	TP	13	HI/PRIV	8	MAI	8	75
BH	PERVIOUS STRIP	SC105,106	$32,413	1,108	$1,274,137	10	YES	10	16/23	8	34.56	5	AN	12	PRIV/MIN	4	TP	13	HI/PRIV	8	MUL	4	74
BH	CONSERVATION AREA	SC105.206	$5,000	1,083	$201,108	20	YES	10	16/23	8		5	BI	15	PRIV/MAJ	0	NP	15	HI/CL	5	NAI	10	88
BH	PERMEABLE PAVEMENT	SC105.207	$87,817	1,843	$2,076,150	10	YES	10	16/23	8	57.46	5	AN	12	PRIV/MAJ	0	TP	13	HI/PRIV	8	MAI	8	74
BHS	BIORETENTION	RD-13	$728,223	269,070	$117,893	20	NO	0	40	10	22,391.49	20	IL	8	PUB.MAJ	8	TP	13	HI/PUB	10	MAI	8	97
BHS	FILTERING TRENCH	RD-13	$961,902	65,430	$640,385	15	NO	0	40	10	5,444.97	15	BI	15	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	96
BHS	IRRIGATION REUSE	RD-13	$48,557	20,397	$103,699	20	NO	0	40	10	2,121.73	10	AN	12	PUB/MIN	10	T+E	10	HI/PUB	10	MAI	8	90
BHS	PERMEABLE PAVEMENT	RD-13	$1,166,711	25,083	$2,026,175	10	NO	0	40	10	782.75	5	AN	12	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	78
BHS	INFILTRATION CHAMBER	RD-13	$551,992	11,500	$2,090,851	10	NO	0	40	10	1,196.26	10	AN	12	PUB/MIN	10	TP	13	LOW	6	MULT	4	75
BHS	GREEN ROOF	RD-13	$1,144,757	4,842	$10,299,194	1	NO	0	40	10	503.65	5	DALS	4	PUB/MAJ	2	T+B	8	LOW	6	MJAI	1	37
BRC	RAINWATER HARVESTING	RD-8	$25,920	2,555	$441,856	20	YES	10	17	4	265.81	5	AN	12	PUB/MIN	10	NP	15	HI/PUB	10	MAI	8	94
BRC	FILTERING TRENCH	RD-8	$51,864	3,390	$666,463	15	NO	0	17	4	282.10	5	BI	15	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	80
BRC	PERMEABLE PAVEMENT	RD-8	$401,449	8,675	$2,015,876	10	NO	0	17	4	270.71	5	AN	12	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	72
BRC	BIORETENTION	RD-8	$157,882	11,598	$592,983	15	NO	0	17	4	965.15	5	IL	8	PUB.MAJ	8	TP	13	HI/PUB	10	MAI	8	71
BRC	INFILTRATION CHAMBER	RD-8	$3,311,954	69,500	$2,075,809	10	NO	0	17	4	72,229.57	20	AN	12	PUB/MIN	10	TP	13	LOW	6	MULT	4	79
BRC	CONSERVATION AREA	RD-8	$5,000	29,739	$7,324	20	NO	0	17	4			BI	15	PUB/MAJ	8	NP	15	HI/PUB	10	NAI	10	82
BRC	GREEN ROOF	RD-8	$423,403	1,816	$10,158,319	1	NO	0	17	4	188.87	5	DALS	4	PUB/MAJ	2	T+B	8	LOW	6	MJAI	1	31

Project ID	Project Type	Subcatchment	Cost (Project Management, Design, Construction)	Target WQv (CFT)	Cost per WQv AC-CFT Treated	Cost Score	Located in Hotspot Sub Catchment (Yes / No)	Hot Spot Score	Subcatchment Percent Impervious	Subcatchment Percent Impervious Score	Bacteria Load Reduction (billion/yr)	Load Reduction Score	Maintenance Burden	Maintenance Burden Score	landowner Cooperation	landowner Cooperation Score	Permitting Burden	Permitting Burden Score	Acceptance/Visibility	Acceptance/Visibility Score	Accessibility	Accessibility Score	Total Score
LCC	BIORETENTION	RD-6	$499,392	38,630	$38,660	20	NO	0	24	8	3,207.67	10	IL	8	PRIV/MIN	4	TP	13	HI/PRIV	8	MAI	8	79
LCC	PERMEABLE PAVEMENT	RD-6	$671,172	14,391	$2,031,623	10	NO	0	24	8	447.76	5	AN	12	PRIV/MIN	4	TP	13	HI/PRIV	8	MAI	8	68
LCC	INFILTRATION CHAMBER	RD-6	$1,304,709	27,300	$2,081,800	10	NO	0	24	8	2,831.43	10	AN	12	PRIV/MIN	4	TP	13	LOW	6	MULT	4	67
LCC	GREEN ROOF	RD-6	$297,950	1,278	$10,157,877	1	NO	0	24	8	132.51	5	DALS	4	PRIV/MAJ	0	T+B	8	LOW	6	MJAI	1	33
MMSBES	BIORETENTION	RD-8,13,14,15	$2,158,157	170,102	$552,665	15	NO	0	17, 40, 23, 25%	10	14,113.56	20	IL	8	PUB.MAJ	8	TP	13	HI/PUB	10	MAI	8	92
MMSBES	FILTERING TRENCH	RD-8,13,14,15	$521,955	34,161	$665,569	15	NO	0	17, 40, 23, 25%	10	2,834.37	10	BI	15	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	91
MMSBES	PERMEABLE PAVEMENT	RD-8,13,14,15	$1,555,615	33,354	$2,031,624	10	NO	0	17, 40, 23, 25%	10	1,037.78	10	AN	12	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	83
MMSBES	INFILTRATION CHAMBER	RD-8,13,14,15	$2,483,965	23,200	$4,663,899	10	NO	0	17, 40, 23, 25%	10	2,406.14	10	AN	12	PUB/MIN	10	TP	13	LOW	6	MULT	4	75
MMSBES	GREEN ROOF	RD-8,13,14,15	$313,632	1,345	$10,158,235	1	NO	0	17, 40, 23, 25%	10	139.49	5	DALS	4	PUB/MAJ	2	T+B	8	LOW	6	MJAI	1	37
MRHS	BIORETENTION	SC142	$3,426,624	270,617	$551,569	15	YES	10	39	10	22,437.12	20	IL	8	PUB.MAJ	8	TP	13	HI/PUB	10	MAI	8	102
MRHS	IRRIGATION REUSE	SC142	$34,301	14,393	$103,810	20	YES	10	39	10	1,491.68	10	AN	12	PUB/MIN	10	T+E	10	HI/PUB	10	MAI	8	100
MRHS	FILTERING TRENCH	SC142	$34,428	1,177	$1,274,102	10	YES	10	39	10	97.59	5	BI	15	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	91
MRHS	PERVIOUS STRIP	SC142	$1,396,151	47,732	$1,274,129	10	YES	10	39	10	1,484.06	10	AN	12	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	93
OHLA	BIORETENTION	SC106,108	$2,177,672	171,648	$552,638	15	YES	10	20%/56%	10	14,320.38	20	IL	8	PRIV/MIN	4	TP	13	HI/PRIV	8	MAI	8	96
OHLA	FILTERING TRENCH	SC106,108	$33,530	2,192	$666,469	15	YES	10	20%/56%	10	182.83	5	BI	15	PRIV/MIN	4	TP	13	HI/PRIV	8	MAI	8	88
OHLA	PERMEABLE PAVEMENT	SC106,108	$1,122,803	24,074	$2,031,622	10	YES	10	20%/56%	10	753.17	5	AN	12	PRIV/MIN	4	TP	13	HI/PRIV	8	MAI	8	80
OHLA	CONSERVATION AREA	SC106,108	$5,000	556	$391,727	20	YES	10	20%/56%	10			BI	15	PRIV/MAJ	0	NP	15	HI/PUB	10	NAI	10	90
PES	INFILTRATION TRENCH	SC11	$97,573	6,377	$666,468	15	NO	0	28	8	653.88	5	BI	15	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	84
PES	PERMEABLE PAVEMENT	SC11	$188,179	4,102	$1,998,314	10	NO	0	28	8	420.59	5	AN	12	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	76
PES	BIORETENTION	SC11	$128,609	9,381	$597,185	15	NO	0	28	8	961.86	5	IL	8	PUB.MAJ	8	TP	13	HI/PUB	10	MAI	8	75
PES	INFILTRATION CHAMBER	SC11	$1,630,886	38,473	$1,846,520	10	NO	0	28	8	3,483.72	10	AN	12	PUB/MIN	10	TP	13	LOW	6	MULT	4	73
PES	GREEN ROOF	SC11	$203,861	874	$10,158,060	1	NO	0	28	8	89.63	5	DALS	4	PUB/MAJ	2	T+B	8	LOW	6	MJAI	1	35
PPT	BIORETENTION	SC11	$499,392	103,898	$209,374	20	NO	0	28	8	3,972.14	20	IL	8	PUB.MAJ	8	TP	13	HI/PUB	10	MAI	8	95
PPT	RAINWATER HARVESTING	SC11	$37,855	757	$2,178,000	15	NO	0	28	8	77.78	5	AN	12	PRIV/MIN	4	NP	15	HI/PRIV	8	MAI	8	75
PPT	PERVIOUS STRIP	SC11	$265,019	17,178	$672,019	15	NO	0	28	8	930.93	5	AN	12	PRIV/MIN	4	TP	13	HI/PRIV	8	MUL	4	69
PPT	PERMEABLE PAVEMENT	SC11	$131,725	2,824	$2,031,640	10	NO	0	28	8	290.19	5	AN	12	PRIV/MIN	4	TP	13	HI/PRIV	8	MAI	8	68

Table 86: Cost and Ranking of Proposed Stormwater Retrofit BMPs (Reduced SWRv) by Project ID and Type

Project ID	Project Type	Subcatchment	Cost (Project Management, Design, Construction)	Target WQv (CFT)	Cost per WQv AC-CFT Treated	Cost Score	Located in Hotspot Sub Catchment (Yes / No)	Hot Spot Score	Subcatchment Percent Impervious	Subcatchment Percent Impervious Score	Bacteria Load Reduction (billion/yr)	Load Reduction Score	Maintenance Burden	Maintenance Burden Score	landowner Cooperation	landowner Cooperation Score	Permitting Burden	Permitting Burden Score	Acceptance/Visibility	Acceptance/Visibility Score	Accessibility	Accessibility Score	Total Score
BELC	FILTERING TRENCH	RD-14	$185,589	12,130	$666,468	15	NO	0	23	8	1,005.46	10	BI	15	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	89
BELC	BIORETENTION	RD-14	$357,581	30,928	$503,635	15	NO	0	23	8	2,563.61	10	IL	8	PUB.MAJ	8	TP	13	HI/PUB	10	MAI	8	80
BELC	PERMEABLE PAVEMENT	RD-14	$106,635	2,286	$2,031,585	10	NO	0	23	8	71.07	5	AN	12	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	76
BGC	PERMEABLE PAVEMENT	RD-13, 14	$194,452	5,043	$1,679,486	10	YES	10	40/23	10	157.78	5	AN	12	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	88
BGC	BIORETENTION	RD-13, 14	$266,976	19,231	$604,726	15	YES	10	40/23	10	1,604.37	10	IL	8	PUB.MAJ	8	TP	13	HI/PUB	10	MAI	8	92
BGC	FILTERING TRENCH	RD-13, 14	$257,100	16,804	$666,468	15	YES	10	40/23	10	1,401.89	10	BI	15	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	101
BH	BIORETENTION	SC105,106	$325,521	25,902	$547,439	15	YES	10	16/23	8	2,153.87	10	IL	8	PRIV/MAJ	0	TP	13	HI/PRIV	8	MAI	8	80
BH	PERVIOUS STRIP	SC105,106	$32,413	1,108	$1,274,137	10	YES	10	16/23	8	34.56	5	AN	12	PRIV/MIN	4	TP	13	HI/PRIV	8	MUL	4	74
BH	PERMEABLE PAVEMENT	SC105.207	$87,817	1,843	$2,076,150	10	YES	10	16/23	8	57.46	5	AN	12	PRIV/MAJ	0	TP	13	HI/PRIV	8	MAI	8	74
BHS	BIORETENTION	RD-13	$728,223	269,070	$117,893	20	NO	0	40	10	22,391.49	20	IL	8	PUB.MAJ	8	TP	13	HI/PUB	10	MAI	8	97
BHS	FILTERING TRENCH	RD-13	$961,902	65,430	$640,385	15	NO	0	40	10	5,444.97	15	BI	15	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	96
BHS	IRRIGATION REUSE	RD-13	$48,557	20,397	$103,699	20	NO	0	40	10	2,121.73	10	AN	12	PUB/MIN	10	T+E	10	HI/PUB	10	MAI	8	90
BHS	PERMEABLE PAVEMENT	RD-13	$1,166,711	25,083	$2,026,175	10	NO	0	40	10	782.75	5	AN	12	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	78
BRC	RAINWATER HARVESTING	RD-8	$25,553	2,555	$435,600	20	YES	10	17	4	265.81	5	AN	12	PUB/MIN	10	NP	15	HI/PUB	10	MAI	8	94
BRC	FILTERING TRENCH	RD-8	$51,864	3,390	$666,467	15	NO	0	17	4	282.10	5	BI	15	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	80
BRC	PERMEABLE PAVEMENT	RD-8	$401,449	8,675	$2,015,876	10	NO	0	17	4	270.71	5	AN	12	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	72
BRC	BIORETENTION	RD-8	$157,882	11,598	$592,983	15	NO	0	17	4	965.15	5	IL	8	PUB.MAJ	8	TP	13	HI/PUB	10	MAI	8	71
BRC	INFILTRATION CHAMBER	RD-8	$2,057,426	43,000	$2,084,220	10	NO	0	17	4	4,472.97	10	AN	12	PUB/MIN	10	TP	13	LOW	6	MULT	4	69
LCC	BIORETENTION	RD-6	$499,392	38,630	$38,660	20	NO	0	24	8	3,207.67	10	IL	8	PRIV/MIN	4	TP	13	HI/PRIV	8	MAI	8	79
LCC	PERMEABLE PAVEMENT	RD-6	$671,172	14,391	$2,031,623	10	NO	0	24	8	447.76	5	AN	12	PRIV/MIN	4	TP	13	HI/PRIV	8	MAI	8	68
LCC	INFILTRATION CHAMBER	RD-6	$627,264	13,000	$2,101,817	10	NO	0	24	8	1,348.30	10	AN	12	PRIV/MIN	4	TP	13	LOW	6	MULT	4	67

Project ID	Project Type	Subcatchment	Cost (Project Management, Design, Construction)	Target WQv (CFT)	Cost per WQv AC-CFT Treated	Cost Score	Located in Hotspot Sub Catchment (Yes / No)	Hot Spot Score	Subcatchment Percent Impervious	Subcatchment Percent Impervious Score	Bacteria Load Reduction (billion/yr)	Load Reduction Score	Maintenance Burden	Maintenance Burden Score	landowner Cooperation	landowner Cooperation Score	Permitting Burden	Permitting Burden Score	Acceptance/Visibility	Acceptance/Visibility Score	Accessibility	Accessibility Score	Total Score
MMSBES	BIORETENTION	RD-8,13,14,15	$2,060,582	162,370	$552,805	15	NO	0	17, 40, 23, 25%	10	13,472.04	20	IL	8	PUB.MAJ	8	TP	13	HI/PUB	10	MAI	8	92
MMSBES	FILTERING TRENCH	RD-8,13,14,15	$521,955	34,161	$665,569	15	NO	0	17, 40, 23, 25%	10	2,834.37	10	BI	15	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	91
MMSBES	PERMEABLE PAVEMENT	RD-8,13,14,15	$1,555,615	33,354	$2,031,624	10	NO	0	17, 40, 23, 25%	10	1,037.78	10	AN	12	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	83
MMSBES	INFILTRATION CHAMBER	RD-8,13,14,15	$200,724	4,000	$2,185,890	10	NO	0	17, 40, 23, 25%	10	414.86	5	AN	12	PUB/MIN	10	TP	13	LOW	6	MULT	4	70
MRHS	BIORETENTION	SC142	$2,548,454	201,029	$552,211	15	YES	10	39	10	16,667.58	20	IL	8	PUB.MAJ	8	TP	13	HI/PUB	10	MAI	8	102
MRHS	IRRIGATION REUSE	SC142	$34,301	14,393	$103,810	20	YES	10	39	10	1,491.68	10	AN	12	PUB/MIN	10	T+E	10	HI/PUB	10	MAI	8	100
MRHS	FILTERING TRENCH	SC142	$34,428	1,177	$1,274,102	10	YES	10	39	10	97.59	5	BI	15	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	91
MRHS	PERVIOUS STRIP	SC142	$1,111,968	38,000	$1,274,666	10	YES	10	39	10	1,181.48	10	AN	12	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	93
OHLA	BIORETENTION	SC106,108	$1,582,468	124,484	$553,746	15	YES	10	20%/56%	10		20	IL	8	PRIV/MIN	4	TP	13	HI/PRIV	8	MAI	8	96
OHLA	FILTERING TRENCH	SC106,108	$33,530	2,192	$666,469	15	YES	10	20%/56%	10	182.83	5	BI	15	PRIV/MIN	4	TP	13	HI/PRIV	8	MAI	8	88
OHLA	PERMEABLE PAVEMENT	SC106,108	$1,122,803	24,074	$2,031,622	10	YES	10	20%/56%	10	753.17	5	AN	12	PRIV/MIN	4	TP	13	HI/PRIV	8	MAI	8	80
PES	INFILTRATION TRENCH	SC11	$97,573	6,377	$666,468	15	NO	0	28	8	653.88	5	BI	15	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	84
PES	PERMEABLE PAVEMENT	SC11	$188,179	4,102	$1,998,314	10	NO	0	28	8	420.59	5	AN	12	PUB/MIN	10	TP	13	HI/PUB	10	MAI	8	76
PES	BIORETENTION	SC11	$128,609	9,381	$597,185	15	NO	0	28	8	961.86	5	IL	8	PUB.MAJ	8	TP	13	HI/PUB	10	MAI	8	75
PES	INFILTRATION CHAMBER	SC11	$1,304,709	27,181	$2,090,880	10	NO	0	28	8	2,786.98	10	AN	12	PUB/MIN	10	TP	13	LOW	6	MULT	4	73
PPT	BIORETENTION	SC11	$431,090	33,247	$564,808	15	NO	0	28	8	3,416.04	10	IL	8	PUB.MAJ	8	TP	13	HI/PUB	10	MAI	8	80
PPT	PERVIOUS STRIP	SC11	$265,019	17,178	$672,019	15	NO	0	28	8	930.93	5	AN	12	PRIV/MIN	4	TP	13	HI/PRIV	8	MUL	4	69
PPT	PERMEABLE PAVEMENT	SC11	$131,725	2,824	$2,031,640	10	NO	0	28	8	290.19	5	AN	12	PRIV/MIN	4	TP	13	HI/PRIV	8	MAI	8	68

6.0 Conclusions

6.1.1 Water Quality Model Results in Context

Watershed loading models are subject to high levels of variability and uncertainty. The model itself is an approximation of reality and the model parameters can be estimated based on available data, established modeling protocols, and assumptions based on professional judgment. There is natural variability in land use and cover, meteorology, and management across the watershed. Furthermore, monitoring data provide an imprecise target for model calibration, as laboratory results are typically grab samples, which may not be fully representative of daily average model predictions. Calibration thus consists of comparing two uncertain numbers, the monitored value and model value. This model was calibrated using available monitoring data. This report discusses ways that the Town can enhance and improve existing flow and bacteria monitoring efforts, which can be used in the future to recalibrate and refine the existing XPSWMM model.

The XPSWMM water quality simulation model calculated FC concentrations for the outfalls at each of the four major Headwaters subwatersheds (Duck Pond, Palmetto Bluff, Rose Dhu Creek, and Stoney Creek) every seven minutes for an entire year (2002 and 2018). Laboratory measurements of FC are typically given as "most probable number" (MPN) per 100/mL or as colony forming units (CFU) per 100 mL. Both units are equivalent but reflect different EPA approved methodologies for counting bacteria cells. For purposes of this report, to distinguish modeled estimates for bacteria, all results were given as "number of FC" (#) per 100/mL. In Regulation 61-68 Water Classifications and Standards, SCDHEC provides limits for FC concentrations for waters designated for shellfish harvesting, such as the May River. These limits are either for a daily maximum concentration (43 MPN/100 mL) or a monthly average (14 MPN/100 mL). The modeled average daily maximum FC concentration in all four subwatersheds was above the SCDHEC standards. In 2002, the XPSWMM water quality model estimated the average maximum daily FC concentrations (the yearly average of the highest predicted FC concentration for each day) as 583 #/100mL for Rose Dhu Creek; 749 #/100mL for Palmetto Bluff; 827 #/100mL for Duck Pond; and 995 #/100mL for Stoney Creek. In 2018 the model estimated daily maximum FC concentrations in the four subwatersheds as 538 #/100mL for Duck Pond; 650 #/100mL for Rose Dhu Creek; 687 #/100mL for Palmetto Bluff; and 932 #/100mL for Stoney Creek.

The results from the water quality model for the May River Headwaters confirms findings from local and relevant studies (Holland et al., 2004; Sanger et al., 2008; and Sanger and Blair et al., 2015) that development (conversion of forested to impervious cover) increases stormwater runoff, which in turn increases pollutant loads, lowers the salinity of receiving water bodies, and promotes the survival of FIB.

- A combination of increased development and climate change may have led to decreased salinity levels (and increased variability) observed in the Headwaters of the May River. Developed and deforested lands have higher levels of freshwater inputs into estuaries, which leads to decreased salinity levels and increased salinity variability (Holland et al., 2004; Montie et al., 2019). Furthermore, studies have shown that lower salinity levels increase the survival rate of fecal coliform bacteria (Chigbu et al., 2014; Lipp et al., 2001; Solic and Krstulovic, 1991).

- Average fecal coliform levels are highest in the Headwaters and decrease moving towards the mouth of the May River (Montie et al., 2019). The fecal coliform levels at SCDHEC shellfish monitoring stations closest to the Headwaters were well above the approved SCDHEC fecal coliform maximum monthly average of 14 MPN/100 mL.
- Fecal coliform levels were higher when salinity levels were lower, and this relationship is strongest at SCDHEC sampling stations closest to the Headwaters (Montie et al., 2019).
- Fecal coliform levels in the Headwaters increased as population levels grew in the Town of Bluffton, and this relationship was strongest at SCDHEC sampling stations closest to the Headwaters (Montie et al., 2019).
- In addition to septic leakage, research (Montie et al., 2019) suggests that the rising levels of fecal coliform in the May River are associated with the loss of forested land and the increase of impervious surfaces and associated stormwater runoff within the watershed. Furthermore, the synergistic nature of urbanization and climate change may lead to further increases in fecal coliform levels in the May River.

There are no loads calculated for these headwater watersheds, and thus these modeled results will serve as a benchmark for future monitoring efforts. The FC load for each subcatchment in each subwatershed is calculated by multiplying the concentration by the corresponding water volume at each time step in the model. Although the modeled FC concentrations are generally higher in 2002 than 2018, the total modeled bacteria load is lower in 2002 as a result of a very large increase in water volume in 2018 (585% increase in annual water volume for the entire Headwaters Watershed region). The increase in runoff is a result of the changes in land use such as the conversion of undeveloped, natural areas to those with more impervious surfaces (in the May River Headwaters, the total amount of impervious surfaces increased from 708 acres in 2002 to 1,876 acres in 2018).

Table 87: Summary of 2018 Fecal Coliform Loadings for Subwatersheds

Subwatershed	2018 FC Load (# FC)
Duck Pond	2.18E+13
Palmetto Bluff	5.84E+13
Rose Dhu Creek	1.48E+14
Stoney Creek	2.47E+14
Total:	4.75E+14

The Project Team also evaluated what load reduction would be required to reduce the concentrations of FC from the 2018 average conditions for Stoney Creek and Rose Dhu Creek. This analysis indicated that a 96.1% and 97% reduction in FC is required for Rose Dhu Creek and Stoney Creek, respectively, to meet the daily maximum concentration threshold for shellfish harvesting (43 MPN/100 mL).

6.1.2 Summary of State of Knowledge

Monitoring bacteria concentrations and calculating loads are the first step in management. Unfortunately, there are many factors that make reduction of bacteria difficult. Residential land uses, which are predominant in the May River Headwaters, tend to produce high bacteria loading for a myriad of contributing factors including leaking septic tanks, pet waste pick-up behavior, as well as turf management and erosion control practices (Wood, 2018). In general, human sewage contamination presents the greatest health risk and is a controllable source (the Town and appropriate partners can fix underperforming septic systems and/or sanitary sewer conveyance systems). However, fecal indicator bacteria (FIB) do not correlate well with the occurrence of pathogens, and they do not identify the source of the contamination. Additionally, many studies – including monitoring efforts by the Town of Bluffton – have documented that FIB can colonize and regrow in biofilms and sediments in the storm drainage system. In other words, it is possible to find FIB in areas where there are not pathogens present; this means the Town could be using resources to treat a problem that may not actually present a human health risk.

Pollutants in stormwater runoff, such as bacteria, can be managed through both structural and non-structural methods. Available information from research indicates that BMP efficiency is variable and dependent on the design, maintenance, and other factors. For example, in some cases a net export of microbes can result due to improper maintenance, regrowth of microbes in the BMP, resuspension during storm events, or direct wildlife deposits (Characklis et al., 2009). Information regarding removal rates of FIB in the International BMP Database (Clary et al., 2010) are variable and dependent on the following, 1) season in which the FIB were quantified; 2) stormwater volume and flows; and 3) the type of FIB being measured. Removal values in coastal SC will most likely be lower than those included in the International BMP Database, which has many studies based on the West Coast. This is primarily due to the following, 1) SC temperature is higher during most seasons than in west coast environments; 2) SC water sources tend to be blackwater and tannic water, which reduces light penetration; and 3) persistent forms of FC are known to grow in the sediments of systems in SC. Furthermore, research has called attention to the nature of temperature-warm, nutrient-rich, stagnant BMPs systems that appear to serve as a reservoir of FIB and at times may also preferentially grow the fecal indicator bacteria.

The International Stormwater BMP database contains approximately 600 pairs of influent and effluent data for fecal coliforms and E. coli. across multiple states. Clary et al. (2008) analyzed the fecal coliform and E. coli data and concluded that the ability of BMPs to reduce FIB varies widely across BMPs. No single BMP appears to consistently reduce FIB concentrations. Additionally, high removal efficiency does not always guarantee attainment of bacteria standards when inflow concentrations are high (Wood, 2018). Across the southeastern region, there is a movement away from stormwater ponds in favor of emphasizing other practices that encourage runoff reduction, which is defined as "the total annual runoff volume reduced through canopy interception, soil infiltration, evaporation, transpiration, rainfall harvesting, engineered infiltration, or extended filtration."

The effectiveness of the New Riverside Pond has been studied by the Town and researchers at USC-Beaufort. The results of this analysis showed that there was a statistically significant reduction in bacteria concentrations between the pond influent and pond effluent. Additionally, there was a statistically significant reduction in FC concentrations at a short distance downstream of the pond outlet, for observations before and after the pond was constructed. However, at the outfall to the May River, the was no statistically significant reduction in FC concentrations before and after the pond was constructed. In other words, even though a large stormwater treatment BMP was installed and effectively removed FC, there was not a benefit to the May River because the bacteria levels still increased downstream of the pond.

In particular, in the face of climate change and sea level rise, it has been important to begin to place tidal influence into the context of stormwater conveyance. The impact of higher tidal elevations in low-lying states such as SC cannot be overstated. This is because the extreme high tides, also known as perigean or king tides, interfere with the conveyance of stormwater to receiving waters. The rising tides have the capability of elevating groundwater levels and increasing saltwater intrusion which can create more frequent or longer duration flooding during storm events; interfere with stormwater conveyance into receiving waters; inundate water, wastewater, and stormwater infrastructure by daily high tide (which promotes corrosion and pipe damage that could cause sewage to seep out of the conveyance system); and adversely impact sanitary sewer pump station functionality. There are multiple ways to address tidal influence at the outset, including installing check valves, locating force mains in specific locations of interest, removing debris in problem areas, and promoting infiltration in creek and watershed restoration plans. Of initial importance are identifying thresholds at which the performance of the stormwater conveyance system is compromised.

The new *Southern Lowcountry Stormwater Design Manual* (Center for Watershed Protection and McCormick Taylor, 2020) will provide the Town with tools, standards, and requirements to help mitigate the effects of future redevelopment and new development in the Headwaters of the May River and in other watersheds in the jurisdiction. Requirements for watersheds in shellfish harvesting areas, like the May River, are the most stringent and necessitate a natural resources inventory, Better Site Design, and retention of the 95th percentile storm (1.95”) on-site.

6.1.3 Project Evaluations

Four septic to sewer conversion projects were evaluated in the Rose Dhu Creek and Stoney Creek subwatersheds: Cahill, Gascoigne, Stoney Creek, and Pritchardville. These projects would overlap with 42 subcatchments in the Stoney Creek watershed and 11 in Rose Dhu Creek. Completion of these projects helps eliminate known sources of human FIB from the May River Headwaters Watershed.

The project team in consultation with the Town decided that the WTM spreadsheet-based model allowed for flexibility to quickly analyze and evaluate a variety of stormwater BMPs, including permeable pavement, bioretention, green roofs, rainwater harvesting, filters, and infiltration trenches and chambers. Eleven project sites (incorporating various individual BMPs) were selected in consultation with the Town (prioritizing subcatchments with bacteria hotspot and/or large impervious areas). All 11 projects were in Rose Dhu Creek (6 projects) and Stoney Creek (5 projects). The prioritized ranking of these projects, based on the Full SWRv is as follows:

1. May River High School (MRHS)
2. One Hampton Lake Apartments (OHLA)
3. Boys and Girls Club of Bluffton (BGC)
4. Bluffton Early Learning Center (BELC)
5. Bluffton High School (BHS)

6. Benton House (BH)
7. Palmetto Pointe Townes (PPT)
8. McCracken Middle School/Bluffton Elementary School (MMSBES)
9. Buckwalter Recreation Center (BRC)
10. Pritchardville Elementary School (PES)
11. Lowcountry Community Church (LCC)

The potential benefits of recommended projects was estimated to be 3.46×10^{13} FC reduction for septic to sewer conversion (only calculates benefits to sewer conversions within the Headwaters), 2.99×10^{14} FC reduction for the Full SWRv stormwater retrofit projects, and 2.53×10^{14} FC reduction for the Reduced SWRv projects. The 2020 estimated costs of these projects is $20.8 million for four septic to sewer conversion projects; $32.7 million for the Full SWRv projects; and $22.6 million for the Reduced SWRv projects.

Table 88: Summary of Estimated Benefits of Projects

Project Type	Potential FC Reduction (#/yr)	Potential FC Reduction (#/yr)
Septic to Sewer Conversion		
Cahill	1.09E+10	1.09E+10
Gascoigne	3.32E+11	3.32E+11
Pritchardville	1.00E+13	1.00E+13
Stoney Creek	2.43E+13	2.43E+13
Stormwater BMP Retrofits	*Full SWRv*	*Reduced SWRv*
Bluffton Early Learning Center	5.04E+12	3.64E+12
Boys and Girls Club of Bluffton	3.55E+12	3.16E+12
Benton House	2.99E+12	2.25E+12
Bluffton High School	3.24E+13	3.07E+13
Buckwalter Recreation Center	9.12E+12	6.26E+12
Lowcountry Community Church	6.77E+12	5.16E+12
McCracken MS/Bluffton ES	2.05E+13	1.78E+13
May River High School	2.55E+13	1.94E+13
One Hampton Lakes Apartments	1.53E+13	1.13E+13
Pritchardville Elementary School	5.61E+12	4.82E+12
Palmetto Pointe Townes	5.27E+12	4.64E+12
Total Bacteria Reduction	**1.67E+14**	**1.44E+14**

If all 15 of the proposed projects were implemented, the XPSWMM and WTM model results indicate there is the potential to remove 1.67×10^{14} FC bacteria/year from stormwater (for Full SWRv) or 2.53×10^{14} FC bacteria/year (Reduced SWRv scenario). This is about 35% and 30% of the 2018 FC load for all four subwatersheds in the May River Headwaters.

All of the septic to sewer conversion projects and stormwater retrofit projects were located in the Rose Dhu Creek and Stoney Creek subwatersheds. The total FC load in 2018 for these two subwatersheds was 3.95×10^{14} FC bacteria/year, which accounts for about 83% of the bacteria load for the entire May River Headwaters. The estimated goals for FC reduction in these two subwatersheds is 96.1% and 97% for Rose Dhu Creek and Stoney Creek, respectively, to meet the daily maximum concentration threshold for shellfish harvesting (43 MPN/100 mL). The combination of septic to sewer conversion with the Full SWRv provides about 50% reduction, which is about half of what would be necessary in these watersheds.

Table 89: Potential Load Reductions in Rose Dhu Creek and Stoney Creek Subwatersheds

Project Type	Potential FC Reduction (#/yr)	Potential FC Reduction (%)
Septic to Sewer Load Reduction	3.46E+13	9%
Full SWRv Load Reduction	1.67E+14	42%
Reduced SWRv Load Reduction	1.44E+14	36%

6.1.4 Recommendations to Reduce FC in the May River Headwaters

Overall, the goal for the Town of Bluffton should be incorporate strategies through Partnerships, Policies, Programs, and Projects in order to implement Better Site Design principles outlined in the new *Southern Lowcountry Stormwater Design Manual.* These strategies include conservation of natural areas, reduction of impervious cover, and management of designated stormwater reduction volumes by infiltration and/or filtration techniques as first priority, or other approved volume reduction techniques as second priority. These recommendations are in agreement with local research (Holland et al., 2004; Sanger et al., 2008; and Sanger and Blair et al., 2015; Sanger and Tweel et al., 2015; Montie, 2019) pertaining to the negative impacts of impervious surfaces in southeastern estuarine environments and are supported with design guidance (such as *Low Impact Development in Coastal South Carolina: A Planning and Design Guide*) and in local ordinances.

Recognizing how expensive these projects are, especially in light of how much load reduction (97%) is estimated to be required, the Town can utilize the process described in Section 5.4.2 in this report as part of the ongoing Water Quality Improvement Program to re-assess areas developed prior to adoption of the *Southern Lowcountry Stormwater Design Manual* guidelines. These projects may be viewed as a “triage” to stop bacteria problems from spreading farther downstream and causing closures of additional shellfish harvesting areas.

In areas where development pre-dated stormwater management requirements or failed to meet on-site retention of the 95th percentile storm, it is recommended the Town of Bluffton should institute an Impervious Area Restoration/Stormwater Retrofit Program in which large impervious areas are targeted to be retrofitted to meet

95th percentile storm retention of impervious surfaces with infiltration BMPs to the maximum extent possible. Additionally, the Town should incorporate Volume Reduction BMPs within existing and future CIP projects to the maximum extent practical, especially for project locations in A/B soils.

In a departure from the recommendations from the 2011 Action Plan, ponds and ditches are not recommended as BMP practices to address bacteria impairment in the May River. Although they do provide important services for flood attenuation and some pollutant removal, they do not promote the infiltration of precipitation, and thus do not provide any runoff reduction (refer to *Southern Lowcountry Stormwater Design Manual*). Stormwater enters the system and leaves at a controlled flowrate, which is advantageous for flood protection but may promote the persistence of FIB downstream of the practice (as has been documented in the literature and the Town's monitoring data).

The Town should also plan projects, policies, programs and partnerships geared at addressing human sources of FIB and mitigating impacts of tidal influence in both the stormwater and wastewater conveyance systems. Strategies for future monitoring projects included in-house microbial source tracking; future bacteria monitoring locations; and water flow monitoring locations. Of initial importance are identifying thresholds at which the performance of the stormwater conveyance system is compromised due to tides and sea level rise. Through analysis of multiple classes of microbial contaminants, the Town can create linear models to compare HF183 (human feces marker), *E. coli*, fecal coliforms, or *Enterococcus* and 12-hr rainfall (as well as incremental aggregate rainfall analyses). When the analysis is completed, the relationships across markers can illustrate patterns of fecal contamination delivery and conveyance. If tidal influence is determined to influence sanitary, septic, and stormwater systems there are several solutions the Town can pursue, including installing check valves, evaluating the location of force mains, removing debris in problem areas, and promoting infiltration in creek and watershed restoration plans.

In the future, the results from the water quality model can be better calibrated if continuous, non-tidal flow data becomes available in key areas of the watersheds. The Town should set up gages for multiple conditions (baseflow, stormflow, wet seasons, dry seasons). A combination of continuous, long-term (one to two years) and shorter-duration monitoring should be conducted. This would allow the model to be compared to an entire hydrograph and sequential hydrographs rather than a single point (a single flow measurement).

As the Town refines the XPSWMM water quality model to reflect enhanced monitoring and completed projects, it will be a useful tool for continuously measuring progress towards achieving FC load reduction in the May Rivers Headwaters and for adaptively managing to changing conditions and knowledge with future Action Plan Updates.

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APPENDIX A:
2019 Technical Report: Historical Analysis of Water Quality, Climate Change Endpoints, and Monitoring of Natural Resources in the May River.

APPENDIX B:
Technical Memo from Dr. Rachel Noble

APPENDIX C:
WTM Spreadsheets

APPENDIX D:
Cost Estimate Spreadsheets